ARSENIC TOXICITY IN BANGLADESH: HEALTH AND SOCIAL HAZARDS

Thesis submitted for the degree of Doctor of Philosophy

By

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April 2003

DECLARATION

I confirm that this thesis is based on original work and no part of the material has previously been submitted by me for a degree qualification in any other university or academic institution. In all cases material from the work of others has been acknowledged and quotations and paraphrases suitability indicated.

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ABSTRACT

Groundwater is the main source of safe drinking water in Bangladesh and presently much of that groundwater is contaminated by arsenic. It is ironic that so many tubewells were installed in recent times for drinking water that is safe from water-borne diseases but that water is now contaminated with toxic levels of arsenic. In a country with regular calamities (floods, tidal storms, famine, disease etc), groundwater arsenic poisoning presents a new dimension of hazard. It is now estimated that as many as 85 million people in Bangladesh are exposed to toxic levels of arsenic in drinking water. The scale is well beyond that of the accident in Bhopal, India in 1984 or Chernobyl, Ukraine in 1986. Arsenic is a known carcinogen and only a small quantity can constitute a serious health hazard.

This thesis seeks to explore the spatio-temporal distribution of arsenic concentrations, risk characterisation in terms of environmental health risk assessment and spatial risk zoning in groundwater of the study area (Ghona *Union* of Southwest Bangladesh). The thesis also explores an understanding of the people's own perceptions in defining 'arsenic toxicity' and the 'consequent impact' of arsenic poisoning on human health and social problems as well as the survival strategies of the arsenicosis patients. In addition, this thesis investigates the inherent policy weaknesses of the government and NGOs.

GIS methodological approaches in terms of spatial analysis and geostatistical analysis were adopted for mapping the 'spatial arsenic concentrations' and 'spatial risk zones'. GLMs were used for the relationships between aquifer depths and arsenic concentrations. In addition, qualitative methodological approaches were explored for aptitude and functionality in identifying the health and inherent social issues of the arsenicosis patients. PRA, the Participatory GIS (PGIS), and participant observation approaches were incorporated in collecting the qualitative data. Informal dialogues with the villagers, in-depth interviews, and focus-group discussions were also employed. The collected water samples were analysed by the FI-HG-AAS method at the SOES, Jadavpur University, Kolkata, India for accurate and reliable results.

The thesis reveals the overall arsenic magnitude and its effects on health and inherent social problems that the arsenicosis patients were experiencing during their illness as well as their survival strategies. The thesis also shows both the short-term and long-term suitable mitigation options. The multi-method approaches adopted in this thesis have been demonstrated and justified as excellent tools to handle a wide range of quantitative and verbatim databases in a meaningful form.

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CHAPTER - I

INTRODUCTION: GENERAL DESCRIPTIONS, AIMS and OBJECTIVES and RESEARCH QUESTIONS

Groundwater is the main source of safe drinking water in Bangladesh and presently much of that groundwater is contaminated by arsenic. The recent discovery of groundwater arsenic poisoning in Bangladesh has aroused widespread concerns since it has been the biggest environmental health disaster in recent times. In a country with regular calamities (floods, tidal storms, famine, disease etc), groundwater arsenic poisoning presents a new dimension of hazard. Resultant health problems were first identified in Bangladesh in 1984. It is now estimated that as many as 85 million of its 125 million people are at risk with arsenic contaminated drinking water (Popham, 2000) in 59 out of 64 districts in the country (Jones, 2000a). The scale is well beyond that of the accident in Bhopal India in 1984 or Chernobyl, Ukraine in 1986 (Smith *et al*, 2000a). So far some 8,000 people have suffered from skin cancers, gangrene, internal damage and many other serious ailments as a result of arsenic poisoning, with many more likely in the future (Hossain, 2001).

The materials presented in this introductory chapter are aimed at providing a general description to the arsenic research issues. The chapter is divided into eleven sections. The first section presents the conceptual issues of arsenic with its properties. Section 1.2 describes the sources of arsenic pollution in the environment. Section 1.3 illustrates the causes of arsenic in groundwater. Section 1.4 explains the toxic and beneficial effects of arsenic. Section 1.5

depicts the worldwide arsenic catastrophe. Section 1.6 discloses the different regulatory limits for inorganic arsenic exposure from drinking water applied in different countries. Section 1.7 argues the rationale of the study. Section 1.8 deals with the aims and objectives of the study. Section 1.9 describes some research questions concerning the aims and objectives; while, section 1.10 describes the selection procedure of the study site and gives a brief geographical description of the study area. Finally, the last section makes some concluding remarks on the overall study concepts.

1.1 ARSENIC and ITS PROPERTIES

Arsenic is a metalloid chemical element in the nitrogen family having the atomic number 33 (ATSDR, 2000) with an atomic weight of 75 (Biswas, 2000), and existing naturally in the earth's crust at low levels (Kartinen and Martin, 1995). It is the 20th most abundant element in the earth's crust and 12th most common in the human body (Kartinen and Martin, 1995). Arsenic, in very small quantities is necessary as a nutrient to humans, but ingesting excessive amounts can be poisonous (Harding, 1983). Although the groundwater arsenic is toxic to humans, through the ages arsenic has been used in medicine, the cosmetics industry and agriculture and has also been used as an insecticide, desiccant, rodenticide and herbicide (Nriagu and Azcue, 1994; DeSesso *et al*, 1998; Evans, 1998; Nikolaidis *et al*, 1998; and Uthus, 1994).

Arsenic compounds were known to the ancients - as early as the 4th century BC when Aristotle wrote of a substance called 'sandarache' - now believed to have been a sulphide of arsenic (Evans, 1998). The first clearly authentic report of the free substance was made in 1649 by Johann Schroeder, a German pharmacist, who prepared arsenic by heating its oxide with charcoal. By the 18th century, arsenic was well-known as a unique semi-metal. Although, compounds of arsenic were known as early as 4th century BC, the element was not identified as such until 1649 (Evans, 1998).

Arsenic occurs in the environment both in inorganic (trivalent or arsenite) and organic (pentavalent or arsenate) forms (Kartinen and Martin, 1995) with different degrees of toxicity (ATSDR, 1990 and Clifford and Zhang, 1994). Arsenic combined with oxygen, chlorine and sulphur is referred to as inorganic arsenic; while organic arsenic is combined with carbon and hydrogen (ATSDR, 2000). Inorganic arsenic is dissolved in groundwater and is more harmful than the organic arsenic present in food (ATSDR, 2000 and DeSesso *et al*, 1998). It is a documented carcinogen and cancers occur chronically after a long-time exposure to even a small amount of daily arsenic intake (Kartinen and Martin, 1995; Goldsmith *et al*, 1972; and Harding, 1983).

1.1.1 Principal compounds

Arsenic is a metalloid, which exhibits both metallic and nonmetallic chemical and physical properties. Arsenic does not often form in its elemental state, but it is associated with many types of mineral deposits and particularly with sulphides. The most common arsenic-bearing minerals are arsenopyrite (FeAsS), orpiment (As_2S_3), realgar (As_2S_2), lollingite ($FeAs_2$), and tennantite ($[Cu,Fe]_{12}As_4S_{13}$), of which arsenopyrite is the most common (Table 1.1). About 60% of the arsenic minerals are arsenates, 20% sulphides and sulphosalts and the remaining 20% include arsenides, arsenites, oxides, silicates and elemental arsenic (Onishi, 1969). Because arsenic has a range of oxidation states from -3 to +5, it can form a variety of different kinds of compounds. Among the most important commercial compounds are the oxides, the principal forms of which are arsenious oxide (As_4O_6) and arsenic pentoxide (As_2O_5) (http://mineral.galleries.com/minerals/elements/arsenic/arsenic.htm).

Arsenic occurs in water in several different forms depending upon the pH and oxidation potential of the water (Kartinen and Martin, 1995). The common species of arsenic are arsenite (As-III), arsenate (As-V), monomethyl arsenic acid (MMAA) and dimethyl arsenic acid (DMAA). The primary valence states for arsenic are 0, -3, +3 and +5. The trivalent forms (As-III e.g. arsenite) and the pentavalent forms (As-V e.g. arsenate) of inorganic arsenic tend to be more prevalent in water than the organic arsenic species (Clifford and Zhang, 1994). Arsenates are more likely to occur in aerobic surface waters and arsenites are more likely to occur in anaerobic ground waters (EPA, 2000a).

Table 1.1
Major arsenic-bearing minerals occurring in nature.

Minerals	Composition	Occurance
Arsenic	As	Hydrothermal veins
Adamite	$Zn_2(OH)(AsO_4)$	Secondary mineral
Arsenolite	As_2O_3	Secondary mineral formed by oxidation of realgar, arsenopyrite and other arsenic minerals
Arsenopyrite	$FeAsS$	The most abundant arsenic mineral
Cobaltite	$CoAsS$	High-temperature deposits, metamorphic rocks
Conichalcite	$CaCu(AsO_4)(OH)$	Secondary mineral
Domeykite	Cu_3As	Found in vein and replacement deposits formed at moderate temperatures
Enargite	Cu_3AsS_4	Hydrothermal veins
Orpiment	As_2S_3	Hydrothermal veins, hot springs, volcanic sublimation product
Realgar	As_2S_2	Vein deposits, often associated with orpiment, clays and limestones.
Safflorite	$(Co,Fe)As_2$	Generally in mesothermal vein deposits
Niccolite	$NiAs$	Vein deposits and norites
Tennantite	$(Cu,Fe)_{12}As_4S_{13}$	Hydrothermal veins
Scorodite	$FeAsO_4.2H_2O$	Secondary mineral
Lollingite	$FeAs_2$	In mesothermal vein deposits
Pharmacosiderite	$Fe_3(AsO_4)_2(OH)_3.5H_2O$	Oxidation product of arsenopyrite and other arsenic minerals

Sources: WHO, 2001.

1.1.2 Arsenic properties

In its most stable free state, arsenic is a steel-grey, brittle solid with low thermal and electrical conductivity. The electronic structure of arsenic atom resembles those of nitrogen and phosphorus. The oxidation state of arsenic is either +3 or -3 depending on the electro-negativity of arsenic and that of the elements with which it is combined (ATSDR, 2000). The main properties of arsenic are:

(a) The inorganic arsenic compounds are solids at normal temperatures and are not likely to volatilise. In water, they range from quite soluble (sodium arsenite and arsenic acid) to practically insoluble (arsenic trisulphide) (http://www.epa.gov).

(b) The lustre of arsenic is metallic and its transparency is crystal and opaque. Its hardness ranges between 3 and 4, its specific gravity is 5.4 - 5.9 and its streak is black (http://www.epa.gov).

(c) Inorganic arsenic is a naturally occurring element in the earth's crust (ATSDR, 2000), and pure inorganic arsenic is a grey-coloured metal, but inorganic arsenic is usually found combined with other elements such as oxygen, chlorine, and sulphur (ATSDR, 2000).

(d) Arsenic does not evaporate and most arsenic compounds can dissolve in water (http://www.epa.gov).

(e) Arsenic gets into the air when contaminated materials are burned, but it settles from the air to the ground and it does not break down, but can change from one form to another (http://www.epa.gov).

1.2 SOURCES of ARSENIC POLLUTION in ENVIRONMENT

Arsenic occurs at a very low concentration in nature, but higher concentrations are associated with anthropogenic sources that may introduce arsenic into food and drinking water. The primary natural sources include geological formations (e.g., rocks, soil, and sedimentary deposits), geothermal activity, and volcanic activity (Figure 1.1). Volcanic activity appears to be the largest natural source of arsenic emissions to the atmosphere (ATSDR, 2000). Arsenic compounds, both inorganic and organic, are also found in food (Gunderson, 1995).

1.2.1 Natural sources

Arsenic is found in natural and anthropogenic sources (Hughes, 2002). It occurs naturally in rocks and soil, water, air, plants and animals. Volcanic activity, erosion of rocks and minerals, and forest fires are natural sources. The terrestrial abundance of arsenic is around 1.5-3.0 mg/kg (Mandal and Suzuki, 2002).

Arsenic in soils: The amount of arsenic that occurs in soil varies considerably from country to country (Table 1.2), from 0.1 to 50 mg/kg at an average concentration of about 5-6 mg/kg (Colbourn *et al*, 1975). Arsenic concentrations in soils are mostly present in sulphide ores of metals including copper, lead, silver and gold (BGS, 1999). Arsenic in soils may originate from parent materials (Tanaka, 1988), but it is present in soils in higher concentrations than those in rocks (Peterson *et al*, 1981). Uncontaminated soils usually contain 1.0-40.0 mg/kg of arsenic with the lowest concentrations in sandy soils and those derived from granites, whereas larger concentrations are found in alluvial and organic soils (Mandal and Suzuki, 2002). The mean arsenic content in Japanese soil is 11.0 mg/kg, in Mexican soil is 14.0 mg/kg, and in Bangladesh soil is 22.1 mg/kg (Table 1.2). The natural level of arsenic in sediments is usually below 10.0 mg/kg and varies considerably all over the world (Mandal and Suzuki, 2002).

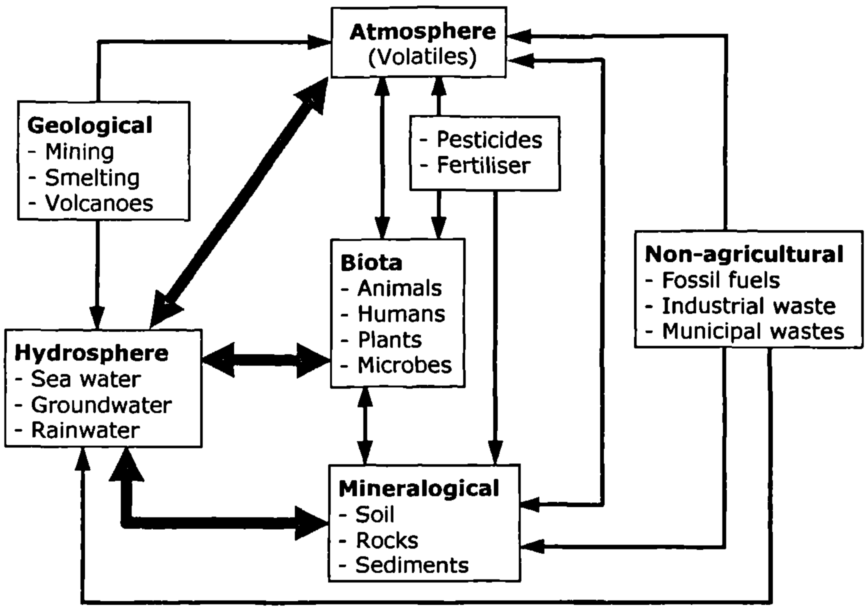


Figure 1.1: Comprehensive transfer of arsenic in environment.
Source: Bhumbla and Keefer, 1994.

The principal factor influencing arsenic concentrations in soils is rock composition. There are many arsenic-containing minerals and the most important ores of arsenic are arsenopyrites ($FeAsS$), realgar (As_2S_2), lollingite ($FeAs_2$), and orpiment (As_2S_3) (Table 1.1). Arsenic concentrations in soils enriched in these ores are often higher than in normal soil (BGS, 1999). The parent materials of soil are usually sedimentary rocks. During the formation of these rocks, arsenic is carried down by precipitation of iron hydroxides and sulphides. Therefore, iron deposits and sedimentary iron ores are rich in arsenic (Maclean and Langille, 1981).

Table 1.2
Arsenic concentrations in soils of various countries

Country	Sample size	Concentration range (mg/kg)	Mean (mg/kg)
Argentina	20	0.8-22.0	5.0
Bangladesh	10	9.0-28.0	22.1
China	4095	0.01-626.0	11.2
India (West Bengal)	2235	10.0-196.0	-
Italy	20	1.8-60.0	20.0
Japan	358	0.4-70.0	11.0
Mexico	18	2.0-40.0	14.0
United States	52	1.0-20.0	7.5

Source: Nriagu and Azcue, 1994.

Arsenic occurs mainly as inorganic species, but it also can bind to organic material in soils (BGS, 1999 and Mandal and Suzuki, 2002). Arsenic may accumulate in soils through the use of arsenical pesticides, herbicide, fertiliser etc. Inorganic arsenic may be converted to arsenic compounds by soil micro-organisms (Wei *et al*, 1991). The total amount of arsenic in soils and its chemical forms has an important influence on plant, animal and human health (Nriagu and Azcue, 1994). Accumulation of arsenic can cause toxic effects to plants and enter the human food chain.

The natural level of arsenic in sediments is usually below 10 mg/kg in dry weight (Mandal and Suzuki, 2002). Arsenic retention and release by sediments depends on the chemical properties of the sediments, especially on the amount of iron and aluminium oxides and hydroxides they contain (BGS, 1999). The amount of sedimentary iron is an important factor that influences arsenic retention in sediments (Mandal and Suzuki, 2002).

Although soil is a source of arsenic in the environment, the main accumulations are in the topsoil layers (Hiltbold, 1975; Woolson, 1983; and Adriano, 1986). According to Nriagu and Azcue (1990), the ultimate fate of the arsenical pesticides depends on: (a) adsorption by inorganic and organic matter in the soil; (b) leaching and removal by runoff; (c) evaporation to the air and drifting to the contaminated soil particles; (d) degradation and methylation of soil micro-organisms; (e) biodegradation and photo-decomposition of organoarsenic compounds in soils; and (f) translocation by means of biological systems to other environments.

Arsenic in water: Arsenic is found at low concentrations in natural water. Seawater ordinarily contains 0.001-0.008 mg/l of arsenic (Cutter *et al*, 2001). In oxic seawater, arsenic is typically dominated by arsenic (V), although some arsenic (III) is invariably present and becomes of increasing importance in anoxic bottom waters (Andreae, 1979; Peterson and Carpenter, 1983; and Pettine *et al*, 1992). Relatively high proportions of arsenious acid (H_3AsO_3) are found in surface ocean waters (Cullen and Reimer, 1989 and Cutter *et al*, 2001). These coincide with zones of primary productivity (Smedley and Kinniburgh, 2002).

The direct sources of arsenic pollution in surface water include domestic and industrial waste water, electric power plants, base metal mining and smelting, and atmospheric fallout of contaminated aerosols; while the indirect sources of pollution include the residues of pesticides and fungicides from soils (BGS, 1999). It should be noted that monosodium methano-arsonate (MSMA) and cacodylic acid (CCA) are highly soluble in water and can be washed away before they are stabilised in soils (BGS, 1999). The common species of arsenic are arsenic (III), arsenic (V), monomethyl arsenic acid (MMAA) and dimethyl arsenic acid (DMAA), but arsenic predominantly presents in groundwater in the form of arsenic (III) and arsenic (V). Methylation of inorganic arsenic to methyl and dimethyl arsenic acid is associated with biological activity in water (Nriagu and Azcue, 1994).

The concentrations of arsenic in unpolluted fresh waters typically range between 0.001 mg/l and 0.01 mg/l, rising to 0.1-5.0 mg/l in areas of sulphide mineralization and mining (Smedley *et al*, 1996). The arsenic speciation was performed on groundwater samples from an area around Alaska containing high levels of arsenic and 3 to 39% contained arsenic (III) and rest were arsenic (V) (Harrington *et al*, 1978).

Geothermal water can be a source of inorganic arsenic in surface water and groundwater. Welch *et al* (1988) identified fourteen areas in the Western United States where dissolved arsenic concentrations ranged from 0.08 mg/l to 15.0 mg/l. Geothermal water in Japan contains 1.8-6.4 mg/l and neighbouring streams about 0.002 mg/l (Nakahara *et al*, 1978). Generally methylated forms of arsenic are not found in groundwater but surface water contains arsenite, arsenate as well as methylated forms of arsenic, i.e. monomethyl arsenic (MMA) and dimethyl arsenic (DMA).

Arsenic in atmosphere: The concentrations of arsenic in the atmosphere are usually low, but are increased by inputs from smelting and other industrial operations, fossil-fuel combustion and volcanic activity (Smedley and Kinniburgh, 2002). Concentrations accounting to around 10^{-5}–10^{-3} µg/m^{-3} have been recorded in unpolluted areas, 0.003–0.18 µg/m^{-3} in urban areas and greater than 1 µg/m^{-3} close to industrial plants (WHO, 2001).

Much of the atmospheric arsenic is particulate, and is usually present as a mixture of arsenite and arsenate (Davidson *et al*, 1985). Total arsenic deposition rates have been calculated in the range of <1–1000 µg/m^{-2}a^{-1} depending on the relative proportions of wet and dry deposition and proximity to contamination sources (Schroeder *et al*, 1987). Values in the range of 38–266 µg/m^{-2}a^{-1} (29-55% as dry deposition) were estimated for the mid-Atlantic coast of the USA (Scudlark and Church, 1988).

There is a little evidence to suggest that atmospheric arsenic poses a real health threat (Smedley and Kinniburgh, 2002), but atmospheric arsenic arising from coal burning has been invoked as a major cause of lung cancer in Guizhou Province of China (Finkelman *et al*, 1999). The human exposure of arsenic through the air is generally very low and normally arsenic concentrations in the air range between 0.0004 and 0.030 $\mu g/m^{-3}$ (WHO, 1996). The amount of arsenic inhaled per day is about ≤ 0.05 $\mu g/m^{-3}$ in unpolluted areas (WHO, 1981). Typical arsenic levels for the European region are currently quoted as being between 0.0002 and 0.0015 $\mu g/m^{-3}$ in rural areas, between 0.0005 and 0.003 $\mu g/m^{-3}$ in urban areas and no more than 0.05 $\mu g/m^{-3}$ in industrial areas (Mandal and Suzuki, 2002).

1.2.2 Industrial sources

Many industries are the sources of arsenic in environment. The application of arsenic herbicides and pesticides represents a primary source of environmental pollution with arsenic. Manufacturing of arsenical pesticides can result in the discharge of arsenic during transportation, distribution and storage to the environment (BGS, 1999). The cumulative quantity of pesticidal arsenic that has been released to the environment is substantial (BGS, 1999).

Major sources of arsenic include wood preservatives, agricultural uses, industrial uses, mining and smelting. The production of chromated copper arsenate (CCA), an inorganic arsenic compound and wood preservative, accounts for approximately 90% of the arsenic used annually by industry in the United States (EPA, 2000a). CCA is used to pressure treat timber, which is typically used for the construction of decks, fences, and other outdoor applications (Smedley and Kinniburgh, 2002).

Apart from this, arsenic and arsenic compounds (arsenicals) are used for a variety of industrial purposes. The burning of fossil fuels, combustion of wastes, mining and smelting, pulp and paper production, glass manufacturing, and cement manufacturing can result in emissions of arsenic to the environment (EPA, 1998a).

1.2.3 Dietary sources

Because arsenic occurs naturally, the entire population is exposed to low levels of arsenic through food, water, air, and contact with the soil. About 10% of inorganic arsenic is found in fish and seafood, while other foods contain the entire inorganic arsenic (NAS, 1999). The inorganic arsenic intake from food in the USA is 1.3 μg/day for infants under one year old, 10 μg/day for 25-30 year-old males, and 12.5 μg/day for 60-65 year-old males (NAS, 1999). In addition, the mean inorganic arsenic consumption for adults is 10.22 μg/day, with a standard deviation of 6.54 μg/day and a range of 0.36-123.84 μg/day based on semi-quantitative food surveys (MacIntosh *et al*, 1997).

1.3 CAUSES of ARSENIC in GROUNDWATER

How does arsenic get into groundwater? When is arsenic dissolved in water? Did arsenic get into groundwater recently? Has water chemistry been changed by recent rapid pumping in Bangladesh to allow arsenic to enter into groundwater? The answers of the questions highlight a huge debate concerning the source and release mechanism of arsenic in groundwater. Arsenic is of natural and geological origin. Arsenic is thought to be closely associated with iron-oxides and it releases from the geological strata underlying Bangladesh. There are two main hypotheses concerning the release of arsenic in groundwater.

1.3.1 The pyrite oxidation hypothesis

Arsenic concentration is especially high in groundwater from pyrite-rich sedimentary aquifers. Due to heavy groundwater withdrawal, allowing oxygen to enter deeper water-bearing strata and inducing the oxidation that leaches out arsenic from arsenopyrite ores (Das *et al*, 1995). Das *et al* (1996) observed arsenopyrite minerals in sediments during their geochemical study in six districts of west Bengal, India bordering Bangladesh. They pointed out that arsenic concentrations in groundwater are from pyrite minerals containing arsenic and bore-hole analyses show the presence of arsenic-rich iron-pyrite in sediment layers. Since iron-pyrites is not soluble in water, the question therefore arises how arsenic from pyrites enters the water. They cited the oxidation of pyrites as the process to release arsenic into groundwater (Figure 1.2). Since pyrite is not soluble in water, it decomposes when exposed to air or in aerated water. A probable explanation is the change of geochemical environment due to high withdrawal of groundwater for irrigation that might have resulted in the decomposition of pyrites to ferrous sulphate, ferric sulphate and sulphuric acid and thus the arsenic in pyrites becomes available.

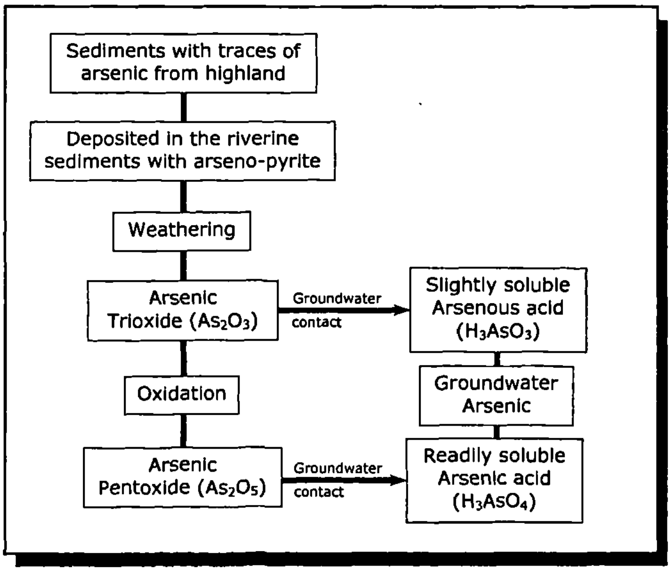


Figure 1.2: Arsenic transformation in groundwater through oxidation process.

During the dry months, due to excessive extraction of groundwater for irrigation, non-recharge, fluctuating water table and millions of boreholes caused by tubewell sinking, the aquifers have become aerated, transforming an anaerobic environment into an aerobic one. Air penetrates from the surface, oxidizes the arsenopyrites and releases arsenic into water. During the rainy season, the aquifers are saturated with water and as such there is very little or no oxygen, and therefore, there is no oxidation of arsenic. As a result there is no or only a very feeble concentration of arsenic in groundwater aquifer (Hossain, 2001). If water is pumped continuously over a long period of time, the quantity of arsenic will gradually increase (Chowdhury *et al*, 1999).

Elevated arsenic concentrations in groundwater are associated with the compaction caused by groundwater withdrawal (Welch *et al*, 1988). In the case of Bangladesh, changes in geochemical environment due to the high withdrawal of groundwater after 1975 at the outset of the 'green revolution' resulted in the decomposition of pyrites which led to release arsenic into groundwater.

1.3.2 The oxyhydroxide reduction hypothesis

Some scientists have disputed the pyrite oxidation hypothesis (Nickson *et al*, 1998 and 2000), explaining that lowering the water table has nothing to do with release of arsenic to groundwater. Such a mechanism is incompatible with the redox chemistry of water. Arsenic produced this way would be adsorbed to Iron oxyhydroxide, the product of oxidation (Mok and Wai, 1994 and Thornton, 1996) rather than be released to groundwater.

Nickson *et al* (1998) proposed the oxyhydroxide reduction hypothesis for the cause (mobilization) of arsenic poisoning in Bangladesh. This theory became well known when it was published in 'Nature' by 1998 and in 'Applied Geochemistry' by 2000 as well as being accepted by the British Geological Survey in 1999.

The release of arsenic to the groundwater derives from reductive dissolution of arsenic-rich hydroxide coatings on sediments. Nickson *et al* (2000) attribute that the reduction of arsenic in oxyhydroxides that were present in sediments washed into valleys cut by rivers when sea-level was lowered during the last glacial maximum (18000 years ago). Arsenic-rich groundwater is mostly restricted to the alluvial aquifers of the Ganges delta. Thus, the source of arsenic-rich iron-oxyhydroxides must lie in the Ganges source region, upstream of Bangladesh. The original sediments had been deposited during Plestocene-Holocenes time and were oxidized and flushed during the low-stand of sea-level during this last glacial maximum. The reduction is driven by microbial degradation of sedimentary organic matter (which is present in concentrations as high as 6% organic carbon) and the redox process that occurs after microbial oxidation of sedimentary organic matter has consumed dissolved-oxygen and nitric acid

(Nickson *et al*, 2000). This hypothesis is based on 46 wells, which were sampled in Bangladesh during May and June, 1997.

1.3.3 Agrochemical hypothesis

Recently, Anwar (2001a), a researcher at Berlin University in Germany, claimed that the indiscriminate use of agrochemicals and fertilizers is causing the groundwater arsenic poisoning in Bangladesh. The Geological Survey of India (GSI) also proposed that the use of phosphate fertilizers is causing arsenic poisoning in Bangladesh, but, the GSI researchers produced no factual data to support their claim (BBC science correspondent Helen Sewell on 6 October 1999). Logically, massive amounts of very high arsenic contaminated agrochemicals and fertilizers would have to be used to be responsible for the scale of groundwater arsenic poisoning in Bangladesh.

1.4 EFFECTS of ARSENIC

Arsenic is a naturally occurring element in the environment having high toxicity in many of its chemical forms and oxidation states, and it causes acute and chronic adverse health effects, including cancer (Hughes, 2002). Arsenic is a well-known poison and as little as 0.1g of arsenic trioxide can be lethal to humans (Jarup, 1992). Arsenic is carcinogenic and only a small quantity can constitute a serious health hazard (BGS, 1999). Its toxicity to humans depends on the concentration and length of exposure. Arsenic is toxic to the human body, but the use of it for industrial and medical purposes is widespread.

1.4.1 Toxic effects

Acute effects: Arsenic has long been known to be acutely toxic. Arsenic toxicity starts in the human body when exposed to an excessive quantity of arsenic. The acute toxicity of arsenic is related to its chemical form and oxidation state. In human adults, the lethal range of inorganic arsenic is estimated at a dose of 1-3 mg/kg of arsenic (Ellenhorn, 1997). The symptoms of acute toxicity include severe vomiting, diarrhoea, bloody urine, muscular cramps, gastrointestinal discomfort, convulsions, facial oedema, cardiac abnormalities (Benramdane *et al*, 1999; Hughes, 2002; and Kamijo *et al*, 1998). Symptoms of acute toxicity may occur within a few minutes to hours of exposure. Arsenic in water at 60.0 mg/l will kill promptly (ATSDR, 2000). People's perception of arsenic is still largely literary, and is most often recognised as a poison of choice for homicide, suicide, and other nefarious activities (NRDC, 2000). This perception of arsenic toxicity represents only its most severe form. When arsenic is ingested in large amounts deliberately or inadvertently, it produces a constellation of severe and often fatal injuries to the cardiovascular, gastrointestinal and nervous systems (NRDC, 2000).

In the acute form of effects, there is a considerable variation among different individuals. Some exposed humans to inorganic arsenic may ingest over 0.150 mg/kg/day, appearing to have no apparent ill-effects, while the characteristic signs of arsenic toxicity begin to appear to some exposed populations ingesting arsenic at oral doses of around 0.02 mg/kg/day (about 1.0 to 1.5 mg/day for an adult) (ATSDR, 1990). Doses of 0.600 to 0.700 mg/kg/day (around 50.0 mg/day in an adult or 3.0 mg/day in an infant) have caused death in some cases (ATSDR, 2000).

Chronic adverse effects: The chronic exposures to arsenic and toxic responses occur at relatively much lower doses than those of producing acute and fatal poisoning. Arsenic and certain arsenic compounds are known carcinogens (EPA, 1988; IARC, 1980 and 1987; and Kitchin, 2001). The amount of arsenic intake that is required to cause a harmful effect depends on the chemical and physical form of the arsenic.

Low-levels of arsenic exposure have non-carcinogenic effects. The non-cancer toxic effects of arsenic include harm to the central and peripheral nervous systems, heart and blood vessel problems, and various skin lesions, such as hyperkeratosis as well as changes in pigmentation (NRDC, 2000). It may cause birth defects and reproductive problems (NAS, 1999).

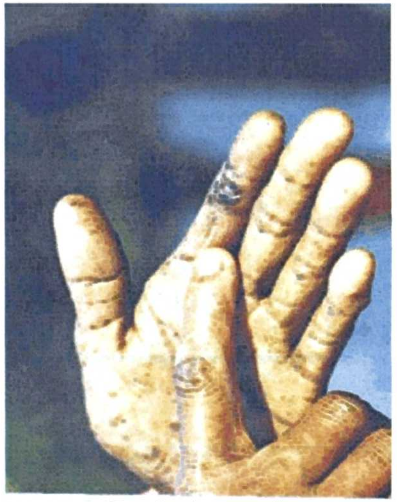
Chronic exposure of human populations to environmental arsenic is also associated with skin cancer and with various internal cancers, such as bladder, kidney, liver, and lung cancer (ATSDR, 2000 and NRDC, 2000). 'Black Foot Disease' in southwest coast of Taiwan, 'Bell Ville Disease' in Córdoba Province of Argentina and 'Kai Dam' in Thailand are well-documented cases of health disorders due to groundwater arsenic poisoning (Figure 1.3). From studies of Taiwan and Chile, it is evident that skin cancers can appear after latency of about 10 years; while, internal cancers, particularly bladder and lung can appear after a latency of 30 years at a concentration of 0.05 mg/l of arsenic (Brown and Chen, 1995; Gou and Lu, 1990; and Tsuda *et al*, 1995).

For inhalation exposure, air concentrations of around 0.2 mg/m^3 are associated with irritation to nose, throat and exposed skin, and higher levels may lead to mild signs of systemic toxicity (ATSDR, 1990). Direct skin contact with arsenic compounds can cause skin irritation, but no reliable dose-response estimates are available on the exposure levels at which these effects begin to appear. The lifelong inhalation of air containing 0.001 mg/m^3 is estimated by the EPA to cause a lung cancer risk of about 0.4% (EPA, 2000b).

1.4.2 Beneficial aspects

Although arsenic is toxic to the human body, it has many economic, industrial and medical uses. Arsenic compounds were employed in bronze alloys as early as 3000 BC and were used for medicaments before 400 BC (BGS, 1999). The Chinese are believed to have used arsenic compounds as insecticides as early as 10th century AD (BGS, 1999). During the middle ages, arsenic compounds were widely used in agriculture and in herbicides (BGS, 1999). Besides, the use of chromated copper arsenate and ammoniacal copper arsenate as wood preservatives was very common until the recent past (Woolson, 1983). The organic arsenic compounds (e.g. herbicide monosodium methanoarsonate (MSMA), disodium methanoarsonate (DSMA), arsonic acid and dimethyl arsenic acid (DMAA) were used in most important pesticides (Wauchope and McDowell, 1984).

CHRONIC ARSENIC IMPACT on HUMAN HEALTH



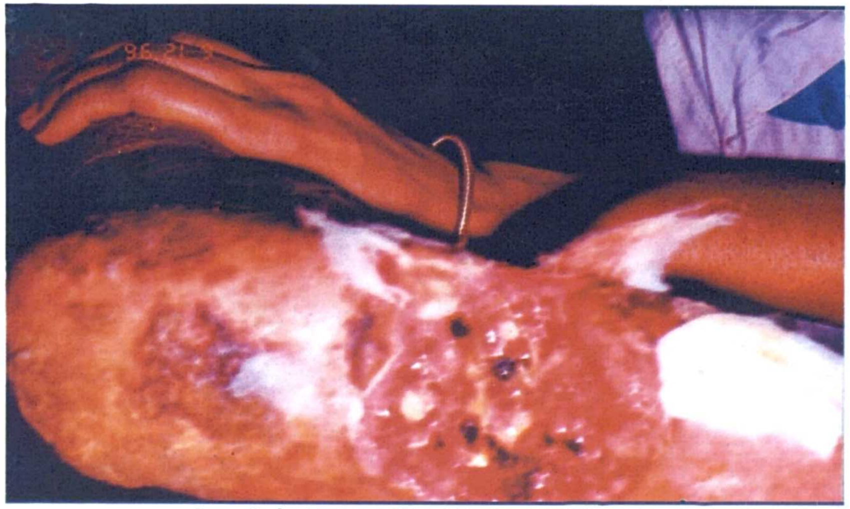
Keratosis on palm
[http://wbln1018.worldbank.org/SAR/]

Arsenic lesions on feet
[http://phys4.harvard.edu]

Arsenic lesions on head
[http://phys4.harvard.edu]

Bowens carcinoma on palm
[http://phys4.harvard.edu]

Hyperkeratosis on palms
[http://phys4.harvard.edu]



Arsenic lesions on feet bleeding open sores
[http://phys4.harvard.edu]

Figure 1.3

Apart from this, arsenic compounds are being used in industries. Arsenic of high purity is used in semi-conductor applications, solar-cells, optoelectronic devices and so on (Nriagu and Azcue, 1994). Phenylarsenic compounds are used in animal feed additives and disease prevention (BGS, 1999). Arsenic trioxide and arsenic salts are used in soil sterilisers, refined arsenic trioxide is used in glassware production, and tertiary arsines are in polymerisation of unsaturated compounds (BGS, 1999). In addition, aromatic arsenic compounds are used in drugs, arsanilic acid in motor fuel, arsonic and arsenic acid are used in the steel industries, and roxarsone is used in feed additives (EPA, 2000b). Moreover, arsenic compounds are present in weed killers, embalming fluids, paints, dyes, soaps, metals, wood preservations, automotive body solder, industrial battery grid, electrophotography etc (EPA, 2000a; and Nriagu and Azcue, 1994).

Arsenic has been used for many years for medicinal purposes. It has been used to be a cure for diseases such as syphilis and some leukaemias. Arsenic can target the product of a genetic lesion behind a specific type of leukaemia. Moderate to high doses (between 0.06 and 0.2 mg/kg/day) of arsenic trioxide given for a period of 30 days can induce remissions in patients with acute promyelocytic leukaemia (Soignet *et al*, 1998 and Zhu *et al*, 1997).

1.5 WORLDWIDE ARSENIC CATASTROPHE

Groundwater arsenic contamination has been reported as poisoning in recent years in many parts of the world (Figure 1.4). The most remarkable occurrences are in parts of Argentina, Bangladesh, Chile, China, India, Mexico, Taiwan and many parts of the USA (Table 1.3). Generally, exposure to arsenic comes from natural and industrial sources, but groundwater arsenic contamination all over the world is discussed as the theme of my research. I will not describe here the arsenic disaster in Bangladesh to avoid repetition of section 1.7.

Table 1.3
Summary of documented arsenic problems in world groundwater.

Country/Region	Area (Km^2)	Population exposed*	Concentrations (mg/l)	Medical symptoms	Aquifer type	Causes of contamination	Reference
Argentina	$1x10^6$	$2x10^6$	<0.001-7.8	Skin lesions and internal cancers	Holocene and loess with rhyolitic volcanic ash	Tertiary-Quarternary volcanic deposits. Volcanic geysers and thermal springs.	Astolfi *et al*, 1981; Nicolli and Merino, 2002; and Smedley *et al*, 1998.
Bangladesh	150,000	$85x10^6$	<0.01-2.5	Keratosis, melanosis, and cancer	Holocene alluvial/deltaic sediments and abundance of organic matter	(a) Pyrite oxidation due to heavy withdrawal of groundwater; and (b) Reduction of iron oxyhydroxides.	BGS, 1999; Nickson *et al*, 2000; and UNICEF, 2000.
India (West Bengal)	Six districts (23,000)	$6x10^6$	<0.01-3.2	Keratosis, melanosis, and cancer	Holocene alluvial/deltaic sediments and abundance of organic matter	(a) Pyrite oxidation due to heavy withdrawal of groundwater; and (b) Reduction of iron oxyhydroxides.	Chakraborti *et al*, 2001; Chatterjee *et al*, 1993; and Das *et al*, 1996.
Chile (Antofagasta)	125,000	$5x10^5$	0.1-1.0	Keratosis, skin cancer, internal cancer	Quaternary volcanogenic sediment	Naturally occurring arsenic from quarternary volcanic sediments.	Borgono *et al*, 1977; Cáceres *et al*, 1992; Karcher *et al*, 1999; Sancha and Castro, 2000.
Taiwan	4,000	$1x10^5$	<0.01-1.82	Black-foot disease and cancer	Sediments, including sulphide bearing black shale	Oxidation pyrite (strongly reducing, artesian conditions).	Guo *et al*, 1997; Kuo, 1968; Tsai *et al*, 1998; and Tseng *et al*, (1968)
China (Inner Mongolia, Xinjiang, and Xinjiang)		$5.6x10^6$	<0.001-2.4	Keratosis, skin pigmentation, cancer	Holocene alluvial and lacustrine sediments	Arsenic is released under reducing environment (strongly reducing conditions, neutral pH, high alkalinity).	Niu *et al*, 1997; Wang and Huang, 1994; Luo *et al*, 1997; Ma *et al*, 1999; and Smedley *et al*, 2001.
Mexico (Lagunera)	32,000	$4x10^5$	0.008-0.620	Pigmentation, keratosis and skin cancer	Volcanic sediments	Oxidation of sulphide [neutral to high pH, mainly arsenic (V)].	Cebrian *et al*, 1983; Del Razo *et al*, 1990; Hernandez-Zavala *et al*, 1998; and Wyatt *et al*, 1998.
Hungary, Romania (Danube Basin)	110,000	29,000	<0.002-0.176	Skin lesions	Quaternary alluvial plain	Reducing groundwater.	Varsányi *et al*, 1991.
Canada	??	??	0.001-0.41	Significant health problems	Ferrous arsenate	Oxidation of arseniferous minwrals. Exchange reactions with ferric oxyhydroxides.	Boyle *et al*, 1998; Koch *et al*, 1999; and Subramanian *et al*, 1984.
USA (Arizona, California, Nevada, Oregon, New Hampshire)	200,000	$3.5x10^6$	<0.001-2.6	Heart disease, nephritis, prostate cancer	Holocene sediments, Holocene mixed Aeolian, some thin volcanic ash bands.	Desorption of iron oxyhydroxides and oxidation of arseniferous minerals.	Robertson, 1989; Thomas *et al*, 1999; Welch *et al*, 1988; and Welch and Ryker, 2000.

* Exposed refers to population drinking water with >0.05 mg/l of arsenic.

1.5.1 Argentina

High groundwater arsenic concentrations have been documented from Córdoba, Salta, Jujuy, La Pampa, and Santa Fe Provinces in Argentina (Astolfi *et al*, 1981; Concha *et al*, 1998; Hopenhayn-Rich *et al*, 1998; and Nicolli *et al*, 1989). Groundwater arsenic concentrations range between 0.006 mg/l and 11.5 mg/l (median 0.255 mg/l) in Córdoba Province (Nicolli *et al*, 1989); between <0.01 mg/l and 0.72 mg/l (mean 0.201 mg/l) in Santa Fe Province (Nicolli and Merino, 2002); and between <0.004 mg/l and 5.28 mg/l (median 0.145 mg/l) in La Pampa Province (Smedley *et al*, 1998 and 2002). Apart from this, the elevated arsenic concentrations are reported from Salta and Jujay provinces in northwestern Argentina (Mandal and Suzuki, 2002).

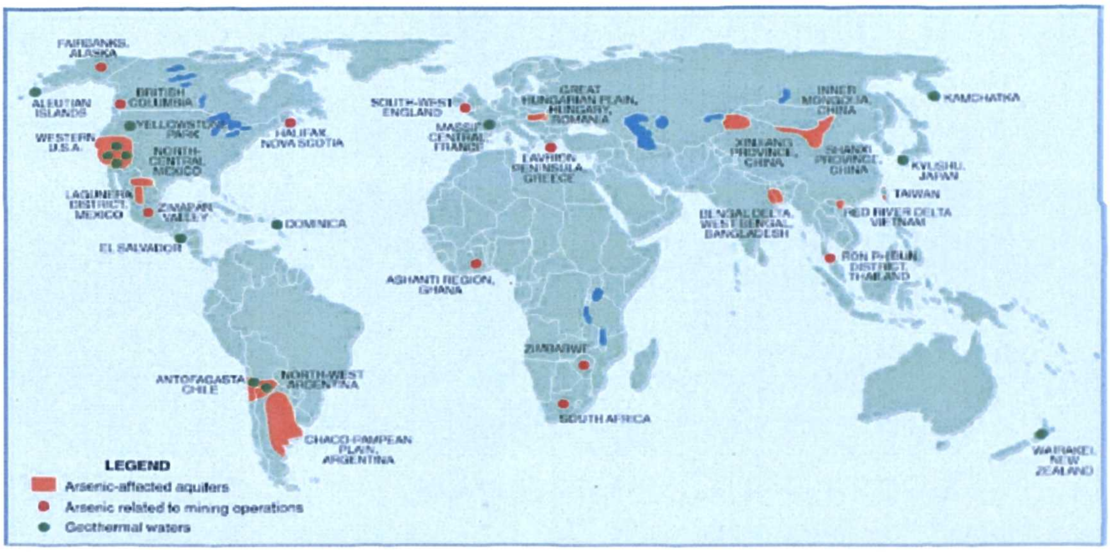


Figure 1.4: Distribution of documented groundwater arsenic problems in major aquifers.
Source: Smedley and Kinniburgh, 2002.

The population of these areas relies heavily upon groundwater for drinking and agricultural production (Smedley and Kinniburg, 2002). The high concentrations of arsenic have been linked with adverse health effects. The occurrence of endemic arsenical skin disease and cancer was first recognised in 1955 (Astolfi *et al*, 1981) and the symptoms of chronic arsenic poisoning, including skin lesions and some internal cancers, have been recorded in these areas

(Hopenhayn-Rich *et al*, 1996a). In Monte Quemado of Córdoba Province, the incident is known as the "illness of Bell Ville" (Astolfi *et al*, 1981). The natural contamination of arsenic in groundwater is related to Tertiary-Quaternary volcanic deposits, together with post-volcanic geysers and thermal springs (Nicolli *et al*, 1989 and Smedley *et al*, 1998).

1.5.2 Chile

High arsenic concentrations have been recorded in the cities of Antofagasta, Calama and Tocopilla of northern Chile (Cáceres *et al*, 1992). Groundwater arsenic concentrations in Antofagasta city range between <0.1 mg/l and 21.0 mg/l (Borgono *et al*, 1977); while in Calama city, it ranges between <0.1 mg/l and >0.8 mg/l (Karcher *et al*, 1999). It is reported that almost 90% of the inhabitants (about 130,000) of Antofagasta city were exposed drinking water with a high arsenic content (0.8 mg/l) in the 1960s and 1970s (Borgono and Greiber, 1972 and Borgono *et al*, 1977).

At the beginning of 1960s, the first dermatological manifestation was recognised in Antofagasta (Borgono and Greiber, 1972). Typical symptoms included skin-pigmentation changes, keratosis, squamous-cell carcinoma (skin cancer), cardiovascular problems and respiratory disease (Zaldivar, 1974). More recently, arsenic ingestion has been linked to lung and bladder cancer (Smith *et al*, 2000b). It has been estimated that around 7% of all deaths occurring in Antofagasta between 1989 and 1993 were due to past exposure to drinking water arsenic at concentrations of about 0.5 mg/l (Smith *et al*, 1998). The aquifers of Chile are composed of volcanogenic sediments and the sources of arsenic have been reported as quaternary volcanogenic sediments, minerals and soil (Cáceres *et al*, 1992).

1.5.3 Taiwan

The southwest coast of Taiwan was identified as a problem area for chronic arsenic exposure (Tseng *et al*, 1968) and the problem has been well known for many years in the 'black-foot disease' endemic area (Chen *et al*, 1985; Guo *et* *al*, 1997; Lu, 1990; Thornton and Farrago, 1997; Tsai *et al*, 1999; and Tseng, 1977). Arsenic problems are also documented in northeastern part of Taiwan (Hsu *et al*, 1997).

In Southwest coast of Taiwan, groundwater arsenic concentrations ranged between 0.01 mg/l and 1.8 mg/l (mean 0.5 mg/l, N=126) and almost half of the samples had concentrations between 0.4 mg/l and 0.7 mg/l (Kuo, 1968); while in northeast Taiwan, the concentrations ranged between <0.01 mg/l and >0.6 mg/l (mean 0.135 mg/l, N=377) (Hsu *et al,* 1997). The chronic arsenicism and cancers are reported in Taiwan (Bates *et al*, 1992; Chen *et al*, 1988a; Guo *et al*, 1997; Lu *et al*, 1975; and Tsai *et al*, 1998).

1.5.4 China

High groundwater arsenic concentrations are associated health problems have been identified in Inner Mongolia, Xinjiang and Shanxi Provinces in China (Lianfang and Jianghong, 1994; Niu *et al*, 1997; Smedley *et al*, 2002; Wang, 1984; and Wang and Huang, 1994). The first cases of groundwater arsenic poisoning were recognised in Xinjiang Province in the early 1980s (Wang, 1984) and the maximum concentration was found in this area by 1.2 mg/l (Wang and Huang, 1994). In Inner Mongolia, excess groundwater arsenic concentrations (>0.05 mg/l) have been identified in Huhhot Basin (Luo *et al*, 1997 and Ma *et al*, 1999) and the maximum concentration has been recorded at 1.5 mg/l (Smedley *et al*, 2001). In a recent study, it has been found that about 40% of the wells samples had arsenic concentrations exceeding 0.01 mg/l (Smedley *et al*, 2001).

Many of the people in these regions drinking high-arsenic have visible skin lesions (Smedley and Kinniburg, 2002). The most worst-affected area is Huhhot, the capital of Inner Mongolia and arsenic-related diseases including keratosis and skin-pigmentation as well as lung, skin and bladder cancer have been identified (Luo *et al*, 1997). At present, the total population exposed to high amounts of arsenic is estimated to be over 2×10^6 and more than 20,000 arsenicosis (an arsenic related disease) patients have been confirmed (Smedley *et al*, 2001).

1.5.5 India

Recent groundwater arsenic exposure has been heavily reported in West Bengal (Bhattacharya *et al*, 1997; Chakraborti *et al*, 2001; Chatterjee *et al*, 1995; Chatterjee and Mukherjee, 1999; Das *et al*, 1996; and Mandal *et al*, 1998), Panjab and Haryana of India (Nordstrom *et al*, 1979). Out of 34,000 tubewells analysed in West Bengal, 40% contain >0.05 mg/l of arsenic (Mandal *et al*, 1998); while in Punjab and Haryana arsenic concentrations range between 0.05 mg/l and 0.545 mg/l (Nordstrom *et al*, 1979).

Several recent studies report that about 6 million people of 2600 villages in 74 arsenic-affected blocks of West Bengal are at risk and 8500 (9.8%) out of 86,000 people examined are suffering from arsenicosis (Chakraborti *et al*, 2001; Mandal *et al*, 1996; Saha, 2001; Das *et al*, 1996; and Bhattacharaya *et al*, 1997). Resultant health problems were first identified in West Bengal in the late 1980s. Skin disorders and skin cancer have also been identified. Around 5000 patients have been identified with arsenic-related health problems in West Bengal although some estimates put the number of patients with arsenicosis at more than 200,000 (Smith *et al*, 2000b). Apart from this, cirrhosis, non-cirrhotic portal fibrosis (NCPE) and extra hepatic portal vein obstruction in adults are very common in Punjab and in Haryana (Datta, 1976 and Datta and Kaul, 1976).

1.5.6 Mexico

Chronic arsenic poisoning was reported in Lagunera of North Mexico during 1963-1983 (Cebrian *et al*, 1983) and the concentrations exposed to the population range between 0.008 mg/l and 0.624 mg/l having an average of 0.1 mg/l (Del Razo *et al*, 1990). High arsenic concentrations have also been identified in groundwater from Sonora in northwest Mexico, where the concentrations range between 0.002 mg/l and 0.305 mg/l (Wyatt *et al*, 1998).

The Lagunera has a well-documented arsenic problem in groundwater with significant resulting chronic health problems. More than 21% of the exposed population out of 200,000 showed at least one of the cutaneous signs (skin pigmentation changes, keratosis and skin cancer) of chronic arsenic poisoning, peripheral vascular disease (black-foot disease), and gastrointestinal disturbances (Albores *et al*, 1979; Cebrian *et al*, 1983 and Hernández-Zavala *et al*, 1998). The source of arsenic in Mexico is assumed to be volcanic sediment (Del Razo *et al*, 1990).

1.5.7 Vietnam

High arsenic concentrations in groundwater and associated health problems have been recorded in Hanoi and in the surrounding rural districts along the Mekong delta of Vietnam (Berg *et al*, 2001 and Wegelin *et al*, 2000). The capital, Hanoi, is largely dependent on groundwater for its public water supply and arsenic concentrations in rural groundwater samples range between 0.001 mg/l and 3.05 mg/l with an average of 0.159 mg/l; while in lower aquifer for Hanoi water supply shows arsenic levels of 0.240-0.320 mg/l (Berg *et al*, 2001). The high arsenic concentrations found in the tubewells (48% above 0.05 mg/l and 20% above 0.15 mg/l) indicates that several million people consuming untreated groundwater may be at a considerable risk of chronic arsenic poisoning (Berg *et al*, 2001).

1.5.8 Canada

High arsenic concentrations have been recorded in Ontario and Nova Scotia, Canada (Grantham and Jones, 1977). Arsenic concentrations in Ontario range between 0.001 mg/l and 0.41 mg/l (Mandal and Suzuki, 2002); while in Halifax County of Nova Scotia, concentrations are found to be >0.003 mg/l (Grantham and Jones, 1977).

Both the areas have well-documented groundwater arsenic poisoning with significant resulting chronic health problems. One person died of arsenic dermatosis in Ontario and in Halifax County and more than 50 families have been affected due to chronic arsenic poisoning (Subramanian *et al*, 1984). Recently, high groundwater arsenic concentrations are reported in British Columbia (Boyle *et al*, 1998; and Koch *et al*, 1999) and in Saskatchewan

(Thompson *et al*, 1999). The source of arsenic in well water is ferrous arsenate (Schlottmann and Breit, 1992).

1.5.9 The USA

Many areas have been identified in the USA with groundwater arsenic problems and most of the worst-affected cases occur in Utah, Western Oregon, California, Alaska, New Hampshire, Nevada, and Arizona (Feinglass, 1973; Frost *et al*, 1993; Harrington *et al*, 1978; O'Rourke *et al*, 1999; Robertson, 1989; Thomas *et al*, 1999; Welch *et al*, 1988; and Welch and Ryker, 2000).

Millard County, Utah is reported to have groundwater arsenic concentrations that range between 0.0018 mg/l and 0.21 mg/l (Southwick *et al*, 1983); while in Central Lane County, Western Oregon, concentrations are between 0.0005 mg/l and 0.17 mg/l (Goldblatt *et al*, 1963). In New Hampshire, concentrations are measured at between <0.003 mg/l and 0.18 mg/l (Peters *et al*, 1999). In Lessen County, California, the present arsenic concentration in drinking water is above 0.05 mg/l (Goldsmith *et al*, 1972) and in San Joaquin Valley, California the concentrations range between <0.001 mg/l and 2.6 mg/l (Fujii and Swain, 1995).

It is reported that arsenic concentrations in Fairbanks, Alaska range between <0.05 mg/l and >0.10 mg/l and 20% of water samples contain >0.10 mg/l (Wilson and Hawkins, 1978). An excess of 0.05 mg/l of groundwater arsenic has been found in Nevada (Fontaine, 1994) and in Arizona (Robertson, 1989). Hypertensive heart disease, nephritis, nephrosis, and prostate cancer are diagnosed among the people of the arsenic-affected areas of the USA (Lewis *et al*, 1999).

Apart from these, some incidents of arsenic poisoning from groundwater have been reported from Hungary (Egyedi and Pataky, 1978 and Nagy and Korom, 1983), Norway (Abdullah *et al*, 1995), New Zealand (Ritchie, 1961), Sri Lanka (Senanayake *et al*, 1972), Japan (Kondo *et al*, 1999), and Finland (Kurttio *et al*, 1999).

1.6 REGULATORY LIMITS for ARSENIC EXPOSURE

Arsenic is necessary to human beings, but an excess can cause harmful effects. Limits on arsenic exposure were set to avoid acute and chronic toxic effects. The arsenic limit set by Bangladesh is 0.05 mg/l (DoE, 1994). Until recently, this standard was also recommended by the World Health Organisation (WHO). But, the WHO has now lowered its recommendation to 0.01 mg/l (WHO, 1994).

The WHO Regulatory Act: The WHO in 1984 issued Guidelines for Drinking Water Quality recommending a maximum value of 0.05 mg/l of arsenic in drinking water (WHO, 1984). However, the discovery of adverse health effects of continuous chronic exposure led the WHO to lower their recommendation to 0.01 mg/l in 1993 (WHO, 1994).

Tseng *et al* (1996) pointed out skin pigmentation and keratosis among people who drank from arsenic contaminated wells in Taiwan; while there has been a very high incidence of lung, bladder and other cancers were found in Taiwan (Chen, 1992) and in Chile (Smith *et al*, 1992). These convinced the WHO to recommend lowering the regulatory level for arsenic in water.

In 1993, the WHO issued another "Guideline Value" for arsenic in minimum safe drinking water at 0.01mg/l, reducing it from 0.05 mg/l on a provisional basis (WHO, 1994). This provisional value now supersedes the "guideline value" of 1984 and is widely recommended as the permissible limit of ingesting arsenic from drinking water (Table 1.4).

EPA (US) Regulatory Act: The first drinking water standard of 0.05 mg/l for the US was set in 1942 by the US Public Health Service. Under the authority of the Safe Drinking Water Act of 1974, the US Environmental Protection Agency (EPA) issued a National Interim Primary Drinking Water Regulation for arsenic of 0.05 mg/l. The EPA sets this standard to protect the health of everybody (http://www.epa.gov/safewater/dwh/health.html).

Guha Mazumder *et al* (1998a) reported that the current maximum contamination level (MCL) of 0.05 mg/l is grossly inadequate for protecting public health and that it therefore requires downward revision as promptly as possible. The arsenic standard for drinking water of 0.05 mg/l set in 1942 could be a total fatal cancer risk of 1 in 100 and does not protect public health and, therefore, requires downward revision as promptly as possible (NAS, 1999). The lower arsenic drinking water standard will protect more people from chronic health effects than the existing standard.

Table 1.4
Current national standards for arsenic in drinking water

Arsenic standard		Countries
<0.01 mg/l	:	Australia (0.007 mg/l) (1996)
0.01 mg/l	:	European Union (1998), Japan (1993), Jordan (1991), Laos (1999), Mongolia (1998), Syria (1994), USA (2001).
>0.01 mg/l but <0.05 mg/l	:	Canada (1999) 0.025 mg/l and Mexico (1994).
0.05 mg/l	:	Bangladesh (1993), Bolivia (1997), China (unknown), Egypt (1995), India (unknown), Indonesia (1990), Philippines (1978), Sri Lanka (1983), UK (unknown), and Viet Nam (1989).

Data source: Smedley and Kinniburgh, 2002.
Parentheses indicate the year for the arsenic standard was established.

In preparing to develop an updated standard for arsenic in drinking water, the EPA collected and compiled over 100,000 arsenic test results taken from 1980 to 1998 from over 24,000 public water systems in 25 US States. These data reveal that arsenic in drinking water poses a significant public health risk and over 56 million people in the 25 states consumed arsenic water above the level of highest acceptable cancer risk (1 in 10,000). On 22nd January 2001, the EPA issued the new "arsenic in drinking water standard" at 0.01mg/l reducing from 0.05 mg/l (Table 1.4) and this new drinking water standard has been recommended to be enforced by 2006 to reduce the adverse health effects of arsenic (EPA, 2001a).

EU Regulatory Act: The present European Union (EU) standard for arsenic permissible limit in drinking water is 0.05 mg/l. In 1998, the EU proposed to lower the permissible limit to 0.01 mg/l (Smedley and Kinniburgh, 2002). In reducing the content of arsenic in drinking water to a risk level of one in a million lifetime risk calculated with a linear dose-response relationship, it is pointed out that the regulatory limit must be 1.5 parts per trillion (ppt) which is not attainable. The European Union (EU) thus plans to enforce a standard of 0.01 mg/l by 2003 to maintain a lifetime cancer risk level of 1 in 10,000. In the United Kingdom, the first regulatory limit of arsenic ingestion was set at 0.15 mg/l in 1900. This was reduced threefold over the next century and until recently, the limit is set at 0.05 mg/l (Table 1.4).

Other Regulatory Acts: An MCL of ≤0.01 mg/l is enforced in Australia (0.007 mg/l), Japan, Jordan, Laos, and Mongolia (Smedley and Kinniburgh, 2002). Canada remains on 0.025 mg/l, while Bangladesh, China, India, Russia, and Sri Lanka are at 0.05 mg/l (BGS, 1999 and Smedley and Kinniburgh, 2002). The Department of Environment (DoE), Government of Bangladesh adopted the provisional value for the MCL of arsenic in drinking water (DoE, 1994).

1.7 NARROWING the FOCUS: RESEARCH TOPIC SELECTION

This section focuses the rationale of the research topic selection i.e. narrowing the focus of the research topic within the broader field of arsenic issues. The question of research topic selection seems to receive less attention than the issues of sampling and data collection methodology. In this section, it is my intention to select the research topic with some criteria, more specifically, I would like to establish an argument in favour of this. How should I select the research topic for study? The following key issues will provide some arguments.

1.7.1 Scale of the problem/Relevance

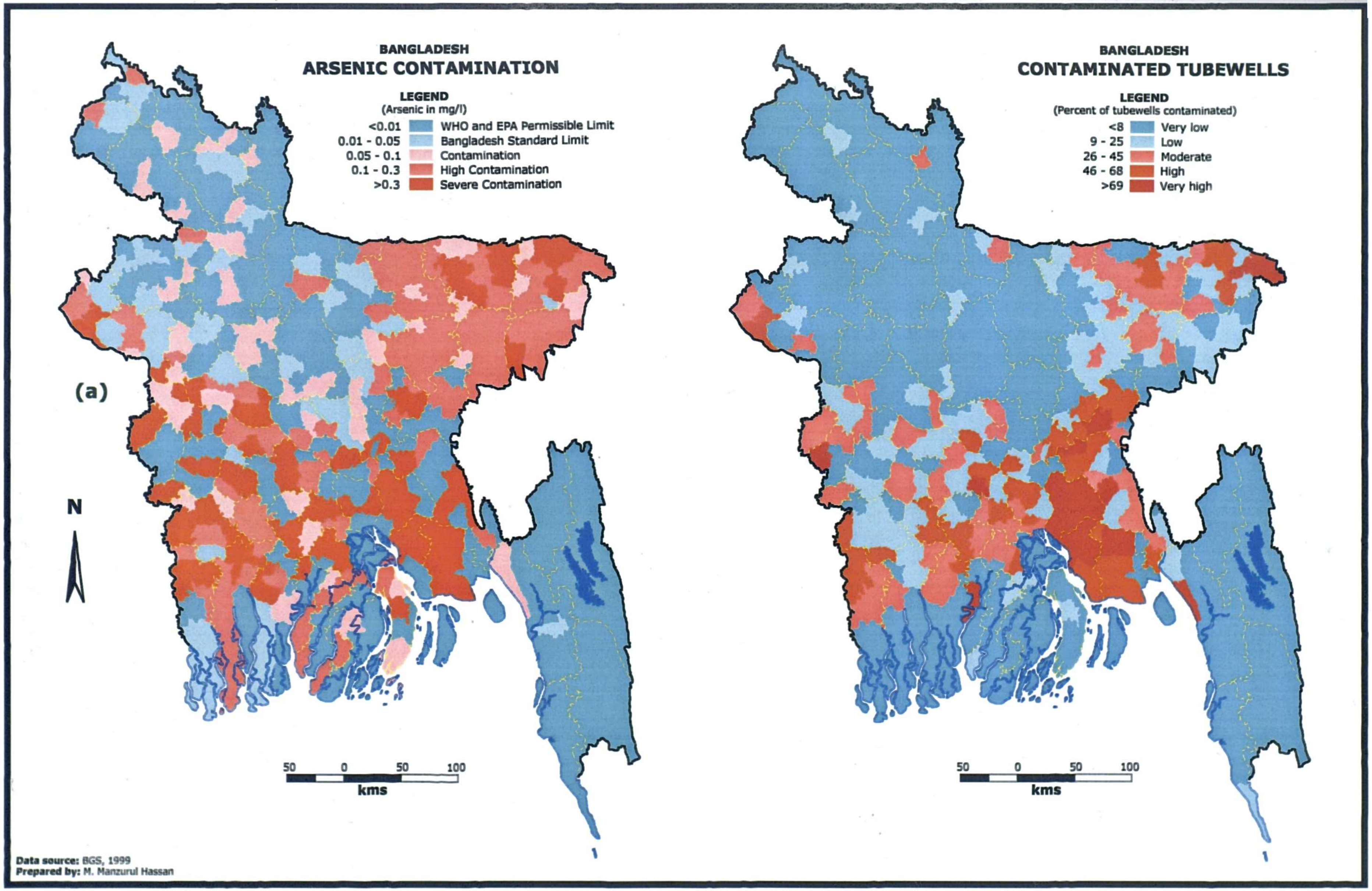
The research topic selection is linked to the present groundwater arsenic contamination in Bangladesh and is also linked to national and local policy in shaping the practices of arsenic mitigation. In a country with regular natural calamities, arsenic toxicity adds a new dimension of hazard in Bangladesh.

The recent discovery of groundwater arsenic in Bangladesh has aroused widespread concerns. Since the discovery of arsenic in 1993 by the Department of Public Health Engineering (DPHE) in Chapai Nawabganj along the western border of Bangladesh with India, the areas of arsenic contamination are increasing at an alarming rate and the risk is spreading all over the country. Extensive contamination was confirmed in 1995 when chronic arsenicosis was being diagnosed by health professionals.

In 1996, arsenic contamination was detected only in 7 districts but this extended up to 48 districts in the middle of 1997 (Hassan, 2000). It is also estimated that about 1.2 million people already have symptoms of arsenic poisoning at a low level (Karim, 2000). Toxic levels of arsenic have been found in the groundwater, affecting millions of people sip by sip, as they drink from hand-operated tubewells established *in the last 20 to 30 years*.

The most arsenic contaminated districts are Chapai Nawabganj, Lakshmipur, Kustia, Faridpur, and Jessore (Figure 1.5). Present arsenic concentrations in Chapai Nawanganj range between 0.05 mg/l and 1.0 mg/l and 70% of the tubewells are unsafe; in Lakshmipur, the maximum concentration stands for 1.11 mg/l and 90% tubewells are at risk; and in Faridpur, the maximum concentration is 1.53 mg/l and 75% tubewells are above 0.05 mg/l (Hassan, 2000).

Apart from this, 79% tubewells in Barisal, 87% in Bagherhat, 72% in Gopalganj, 78% in Jessore, 74% in Rajbari, and 70% in Satkhira are above 0.05 mg/l of arsenic (Hassan, 2000). It is reported that about 25 million people of 2000 villages in Bangladesh are at risk and 3695 (20.6%) out of 17,896 people examined are suffering from arsenicosis (Nickson *et al*, 2000 and Tondel *et al*, 1999).



BANGLADESH
ARSENIC CONTAMINATION
LEGEND
(Arsenic in mg/l)
<0.01 WHO and EPA Permissible Limit
0.01 - 0.05 Bangladesh Standard Limit
0.05 - 0.1 Contamination
0.1 - 0.3 High Contamination
>0.3 Severe Contamination
(a)
N
50 0 50 100
kms
BANGLADESH
CONTAMINATED TUBEWELLS
LEGEND
(Percent of tubewells contaminated)
<8 Very low
9 - 25 Low
26 - 45 Moderate
46 - 68 High
>69 Very high
50 0 50 100
kms
Data source: BGS, 1999
Prepared by: M. Manzurul Hassan

Figure 1.5

Arsenic pollution is causing not only a health hazard to individuals but also widespread social problems (Figure 1.6). The social incidence of arsenic poisoning among different people has caused serious problems in Bangladesh (Hassan, 2000). These include disrupted family life, the difficulty of arranging daughters' marriages, a lack of job offers for arsenic affected qualified candidates, and so on (Bearak, 1998; Chowdhury, 1997; Haq, 1999; Milton *et al*, 1998; WHO, 1996; and World Bank, 1999).

"Why should I work when I'm going to die", asks this villager.
Source: http://news.bbc.co.uk/1998..

"You only come and take our photo, you do nothing to alleviate our pain," she said.
Source: http:// news.bbc.co.uk/1998..

Figure 1.6: Examples of social impacts due to chronic arsenic poisoning.

There is a tendency for unaffected people to maintain a safe distance from arsenic-affected people since they think that arsenicosis is like leprosy or another contagious disease (Hassan, 2000). In rural Bangladesh, the people or communities affected by arsenicosis become almost isolated. In this connection, the author decided to focus his research on 'arsenic issues' since a review of the literature suggested a gap in the area of environmental health risk and social hazards.

1.7.2 Database

Many research organisations, groups and individuals now working on arsenic issues specialise in arsenic removal technology rather than health and social hazards. They mainly focus their research on arsenic problems with chemistry, geology, medical science, engineering and so on. There is no work on arsenic using geographical perspectives. However, the existing arsenic information in Bangladesh is not consistent. Various organisations have collected data using a variety of different analytical procedures and most of them have not followed any scientific and/or statistical methods.

Almost all of the research outputs available for Bangladesh are based upon water samples analysed for arsenic contamination that have been randomly selected. Since arsenic concentration in groundwater is very uneven with regards to its space-time characteristics, the selected tubewells in any geographical location often therefore do not reflect the real proportion of wells or area contaminated.

Besides, there have been problems in analysing arsenic concentrations because of the variability of different arsenic test kits in terms of their measurement procedures and measurement scales. So far, very few studies have been made in any consistent and logical way on the arsenic related social problems. There is a need for in-depth micro level research to study these problems and to help us understand the complexity of the problems faced.

1.7.3 Ethics

The ethics of this research topic need to be considered. In choosing the study topic on arsenic issues, I made this decision with what I considered to be a considerable ethical compromise. The main issue in this regard is that where local people are suffering from chronic illness and are socially isolated. Is it ethical for me to select the issues for research without directly helping the arsenic affected people? The answer is yes, because it is felt that the research will eventually lead to a better understanding of the nature of the social context of the arsenic hazard and will therefore assist with planning. Any direct intervention, such as the release of data to the public on the contamination of individual tubewells, would be appropriate because it would provide people with an awareness about the toxic nature of arsenic.

1.8 AIMS and OBJECTIVES

The aim of this study focuses on the question "what motivated the research?" In answering the question, the overall aim is to explore the impact of arsenic toxicity, especially in the context of the existing health and social conditions. Apart from this, the aim is to gain an understanding of the people's own perceptions in defining 'arsenic toxicity' and the 'consequent impact' on their health and social potential. The main objectives of this study are:

(a) **To identify the scale of arsenic concentrations and spatial distribution in the study area.** This objective will be fulfilled by mapping the geographical distribution of arsenic magnitude based on demarcating low to severe arsenic contaminated areas. Furthermore, mapping will be conducted of the micro-level spatial pattern of arsenic magnitude in terms of 'hot spots' using spatial interpolation methods. The predicted 'iso-arseno' value lines could be helpful in identifying the 'safe zones' and 'contamination zones'. Apart from this, a relationship between arsenic concentrations and aquifer depth will be analysed to uncover whether deep aquifers are safe or not.

(b) **To assess the environmental health risk developed by excess intake of arsenic.** This is an important target for the present study. The investigation of health impacts on human beings due to arsenic pollution in different stages (i.e. stage 1: melanosis and keratosis; stage 2: leukomelanosis and hyperkeratosis; and stage 3: gangrene and cancer) will be helpful in measuring the chronic effects of arsenic poisoning. The exposure assessment, toxicity assessment and risk-ratio will be calculated in order to assess the actual health risk in the study area. The spatial 'risk-pattern' will also be mapped in order to assist mitigation.

(c) **To analyse the experience of health problems arising from living with arsenic.** Local people's perceptions about arsenic and its impact on health will be of great help in revealing the real impact of arsenic on human health, especially what they think about environmental health risks and what has changed in the last years since arsenic was first identified in the study area. In addition, people's perceptions about coping and adaptive strategies will uncover their experiences of living with arsenic poisoning.

(d) **To analyse the social impacts in the study area which result from arsenic toxicity.** The investigation of the change of social norms of the arsenic affected people could be helpful in identification of the overall social hazards in the study area. Immeasurable family problems in terms of issues in conjugal life, divorce, separation, problems in getting married for young unmarried women and different types of problems in getting jobs are also important social hazards. Apart from this, the survival strategies that they envisage show how they manage their social problems.

(e) **To analyse the policy response to the arsenic problem that has been forthcoming from central and local government, and various non-government organisations (NGOs).** Here I will focus on the policy response by government and NGOs about arsenic mitigation. Personal and in-depth interviews were conducted with the relevant government and NGO officials and people's own opinions about the existing plans of government and NGOs were compiled. This will help to find out the inherent policy weaknesses and will assist in developing strong recommendations for both short-term and long-term mitigation.

1.9 RESEARCH QUESTIONS

The topic of this research is made timely by the current scientific interest in exposure to and adverse health and social effects from arsenic in Bangladesh.

Moreover, environmental risk and public policy in this regard is also of major interest. What databases are needed properly to assess the health as well as social impacts of inorganic arsenic - qualitative or quantitative or a combination of both? In fact, both qualitative and quantitative techniques were employed for this research.

In order to fulfil the objectives, several related issues in the form of research questions need to be considered, i.e. what are the main research questions and why? In thinking about the differences between the qualitative and quantitative analytical procedures, I have decided to identify the research questions for the two approaches separately.

I. Research questions for the qualitative approach.

(a) **How do local people manage the health situation developed by chronic arsenic ingestion?** This question covers answers relating to the health conditions of the local people. Furthermore, the study will find people's ideas about the management of arsenic poisoning (i.e. what local people think and do, not what the doctors and health workers, NGOs or someone else, do or think). Determining how and to what extent the patient's actions are influenced by others is a part of what I want to uncover. This will help to focus the policy response to the local government and NGOs.

(b) **How do arsenic-affected people live with social hazards?** This question allows exploration of the inherent social problems of arsenic-affected people. The study will focus on the people's perceptions regarding the various social problems created by arsenic in recent times. This question will identify and determine how and to what extent people are getting help from different sources at the local level. This question will explore the role of government and NGOs as well as the other international organisations in solving the social problems and by mitigating arsenic toxicity.

II. Research questions for the quantitative approach.

(a) **What should be the standard measurement to identify the low to severe arsenic concentrations?** This question addresses the standard permissible limit of taking arsenic from groundwater. The WHO (1994) and the EPA (2001a) have issued different "Guideline Values" for arsenic ingestion in drinking water. Both of the guidelines set the maximum limit of taking arsenic at 0.01 mg/l; while the DoE (1994) has set the value at 0.05 (mg/l) for Bangladesh standard maximum tolerable limit for groundwater arsenic. Astolfi *et al*, (1981) pointed out that the regular intake of drinking water containing more than 0.1 mg/l of arsenic leads to clearly recognisable signs of arsenic toxicity and ultimately in some cases to skin cancer.

Tsuda *et al* (1995) claim that exposure to 5 years of high dose of arsenic (>0.1 mg/l) can cause skin signs of chronic arsenicism for subsequent cancer development. Buchet and Lison (1998) concluded that a low to moderate level of environmental exposure to inorganic arsenic (0.02-0.05 mg/l) from drinking water does not have any dose-response relationship for arsenic and cancer. Moreover, it is reported from studies of the USA in the 1970s (Goldsmith *et al*, 1972; Harrington *et al*, 1978 and Morton *et al*, 1976) that no clinical or haematological abnormalities were observed in the exposed population, despite the presence of higher arsenic concentrations in groundwater (i.e. >0.05 mg/l). This raises questions for the identification of arsenic 'magnitude zones' and 'risk zones'.

(b) **Which areas are 'contaminated' and which areas are 'safe'?** The areas over the permissible limit of Bangladesh standard arsenic concentration (0.05 mg/l) will be identified as 'contaminated' areas; while the areas are below 0.05 mg/l could be the 'safe' areas. In addition, the WHO (1994) and the EPA (2001a) "guidelines values" for arsenic ingestion in drinking water will also be considered in identification of contaminated and safe areas.

(c) **What possible factors are responsible for spatial variation of arsenic?** Arsenic magnitudes have complex space-time patterns. This research question seeks to discover some of the geographical factors responsible for the variation of arsenic magnitudes.

(d) **How can arsenic and relevant health and social data be accurately and efficiently assessed?** This question is linked to the arsenic analysis processes and the qualitative and quantitative approaches. Arsenic concentrations in groundwater were analysed by laboratory methods. This was the appropriate technique for analysing arsenic magnitudes from groundwater. Yet for making a projection for future toxicity of arsenic, it is difficult to identify the level of actual intake of arsenic and how long people have been ingesting it.

1.10 THE STUDY AREA: SAMPLE STUDY SITE SELECTION

1.10.1 Approaches to study site selection

This section focuses on the question of sampling site selection for detailed and in-depth analysis. The methods of drawing study sites are mainly based on the 'purposive or theoretical sampling criteria' rather than the 'statistical probability approach' (Figure 1.7). There are varying accounts of principles applicable to study site selection, but diversity also results from many different methods of sampling (Curtis *et al*, 2000). Although the literature includes very useful discussions of the 'sampling strategies' (Baxter and Eyles, 1997; Curtis *et al*, 2000; Kuzel, 1992; Miles and Huberman, 1994; Patton, 1990; Stake, 1994; Trost, 1986; and Wainwright, 1997), the question of sample study site selection receives less attention than methodological issues of data collection and data analysis.

In this study, the sampling strategy will mainly be based on qualitative criteria, since there is a lot of heterogeneity in arsenic concentrations. It is essential to maximise the 'validity' and 'generalisability' by selecting a 'typical site' (Ward-Schofield, 1993) for qualitative research. In qualitative research, is it realistic to identify a 'typical site' for research without conducting at least a basic reconnaissance of all potential sites?

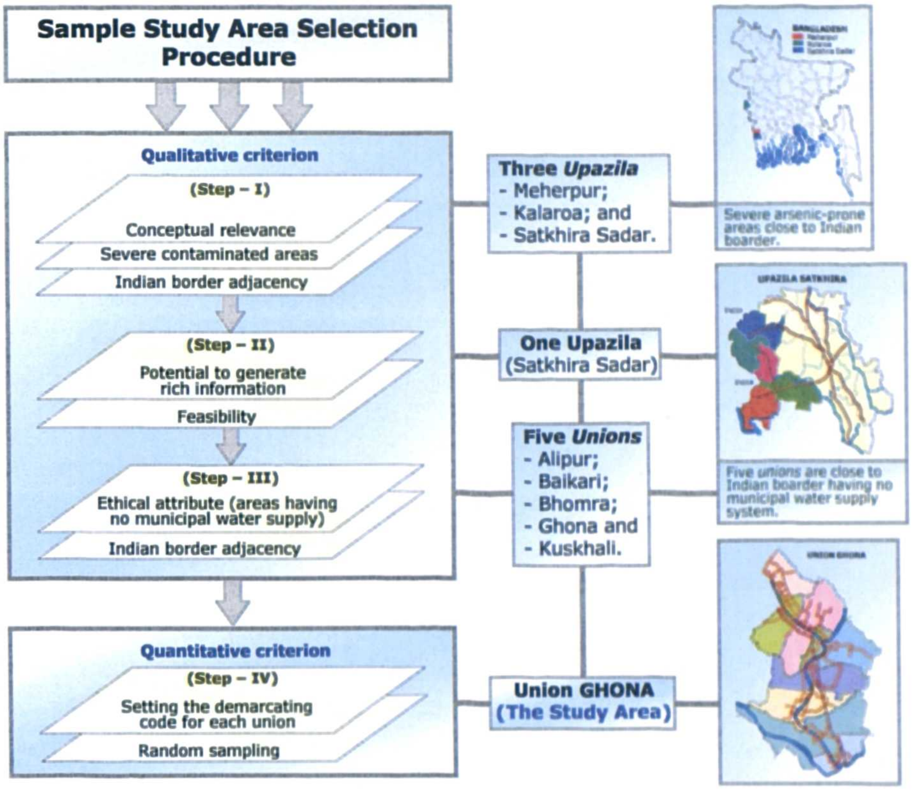


Figure 1.7: Study Site Selection Strategy.

Generally, the sample selection is conceptually driven either by the theoretical framework, which underpins the research question from the outset, or by an evolving theory, which is derived inductively from the data as the research proceeds (Curtis *et al*, 2000). My study sample site selection was designed to make possible 'analytic' and 'statistical' generalisation. The objective of the sample size selection is based mainly on the qualitative guidelines that have been proposed by different authors (Baxter and Eyles, 1997; Jorgensen, 1989;

Miles and Huberman, 1994; and Wainwright, 1997). Beside this, a quantitative approach has also been considered for unbiased site selection (Figure 1.7).

(a) Is the sampling strategy relevant to the conceptual framework (Miles and Huberman, 1994)?

(b) Is the sampling strategy for the research site selection based on reconnaissance survey (Wainwright, 1997)? Or, is it based on rich information?

(c) Is the sampling plan for the study site selection feasible (Miles and Huberman, 1994)? Or, is the selected sample study site favourable for front-end-management?

(d) Is the selection procedure of the sample study site ethical (Miles and Huberman, 1994)? And

(e) Is the selected study site 'representative' (Jorgensen, 1989) for macro level information?

The selection of the possible study site is primarily based on the conceptual framework of the arsenic issues supported by relevant literatures. A reconnaissance survey is important in sample study site selection. I had not conducted a reconnaissance survey, but available published and unpublished information were reviewed. The selection of Satkhira in southwest Bangladesh was shaped most clearly by the published information regarding the arsenic issues. The BGS (British Geological Survey) and the UNICEF (United Nations International Children's and Educational Fund) conducted a sample survey for tubewell water screening on a random basis and in both >80% of the tubewells were recorded as highly contaminated with arsenic. Besides, it is noted that the first arsenicosis patient was identified from Satkhira in 1984 and since 1993 arsenic contamination has been increasing at an alarming rate and the risk is spreading all over Bangladesh. Moreover, the area is located adjacent to the

Indian (West Bengal) border, across which there is a continuation of the arsenic calamity of the Ganges delta.

Ease of access is an essential component for study site selection. This requirement corresponds to Miles and Huberman's 'feasibility' attribute. Managing the relationship with informants, or 'front-end-management' (Wainwright, 1997), is an important aspect of participatory qualitative research validity. In qualitative data collection procedure through single in-depth interviews, focus groups, and participatory rural appraisal (PRA), it is essential to establish a friendly relationship between me and the informants, which may last several weeks or months. To save time and energy in the participatory research, a study area was chosen where the environment is already familiar to me.

The study villages were selected at locations outside the piped municipal drinking water system, which were arsenic-free. People outside the municipal areas use groundwater and surface water for their regular needs. The geographical area for study to some extent must be representative of national issues. Therefore, I decided to follow purposive sampling in place of a random sampling procedure. But, at the *mauza*[1] level, I followed a random sampling procedure in selecting the study sites. The strength of the case study method links particular places referred to in the regional and national accounts to the local social contexts surrounding arsenic contaminated areas. For the final site, I selected a place whose reputation for arsenic toxicity is still current.

On the basis of the sample site selection procedures and key questions, I have developed a potential list of probable study sites in the areas of high arsenic concentrations and areas having Indian border (West Bengal) adjacency since it is proved from various reports that the Ganges delta is highly contaminated with

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[1] The lowest level administrative territorial unit (below division, district, *Upazila* and *union*) in Bangladesh having separate jurisdiction list numbers (JL No) in the revenue records. Every *mauza* has each well demarcated on a cadastral map. A *mauza* consists of one or more villages, depending on their population size. Generally, the average population of a *mauza* is about 1000.

arsenic. These are Meherpur, Kalaroa and Satkhira *Sadar Upazila*[2]. Having selected these sites, I followed the feasibility attribute and selected Satkhira *Sadar Upazila* for the study. Satkhira *Sadar Upazila* consists of 15 *Unions*[3] having about 7,000 tubewells. Since it was difficult to manage the whole area for data collection, I selected those *unions* which have no municipal safe drinking water facilities and are adjacent to the Indian border. Alipur, Baikari, Bhomra, Ghona and Kuskhali satisfied these criteria (Figure 1.7).

Satkhira Municipality provides arsenic-free safe drinking water to the people living within the municipal area but the rest of the area of Satkhira *Sadar Upazila* remains at risk. The final choices for a study site selection resulted from the quantitative sampling strategy. In a quantitative approach, the sampling strategy for site selection was unbiased and following the random sampling criteria, I selected Ghona *Union* of Satkhira Sadar *Upazila* in Satkhira district as the study site for this thesis (Figure 1.7). The overall selection criteria for a 'study area' are important in selecting a study site in geographical research.

1.10.2 General description of the study area

The selected study area is located in Southwest Bangladesh, having about two kilometres of international border with West Bengal, India. The study area is a part of the Satkhira *Sadar Upazila* located 20 kilometers west of the *Sadar Upazila* Headquarters (municipality) and is connected with the municipality by the Satkhira-Baikari road (Figure 1.8). The study area lies between 22°41'11" and 22°45'06" north latitude and 88°57'09" and 88°59'42" east longitude (Figure 1.8). The area is bounded by Baikari *Union* on the north and west; Kushkhali *Union* on the northeast; Shibpur *Union* on the east; Alipur *Union* on the south;

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2 The 3rd order (below division and district) local government administrative unit in Bangladesh. Originally, it was a 'police station' which subsequently developed in a revenue/development circle. It consists of a number of *unions*. There are 460 *upazilas* in Bangladesh.

3 The 4th order (below division, district and *upazila*) local government administrative unit in Bangladesh. It consists of a number of *mauzas*. It has an average area of 12 square miles with an average population of about 30,000.

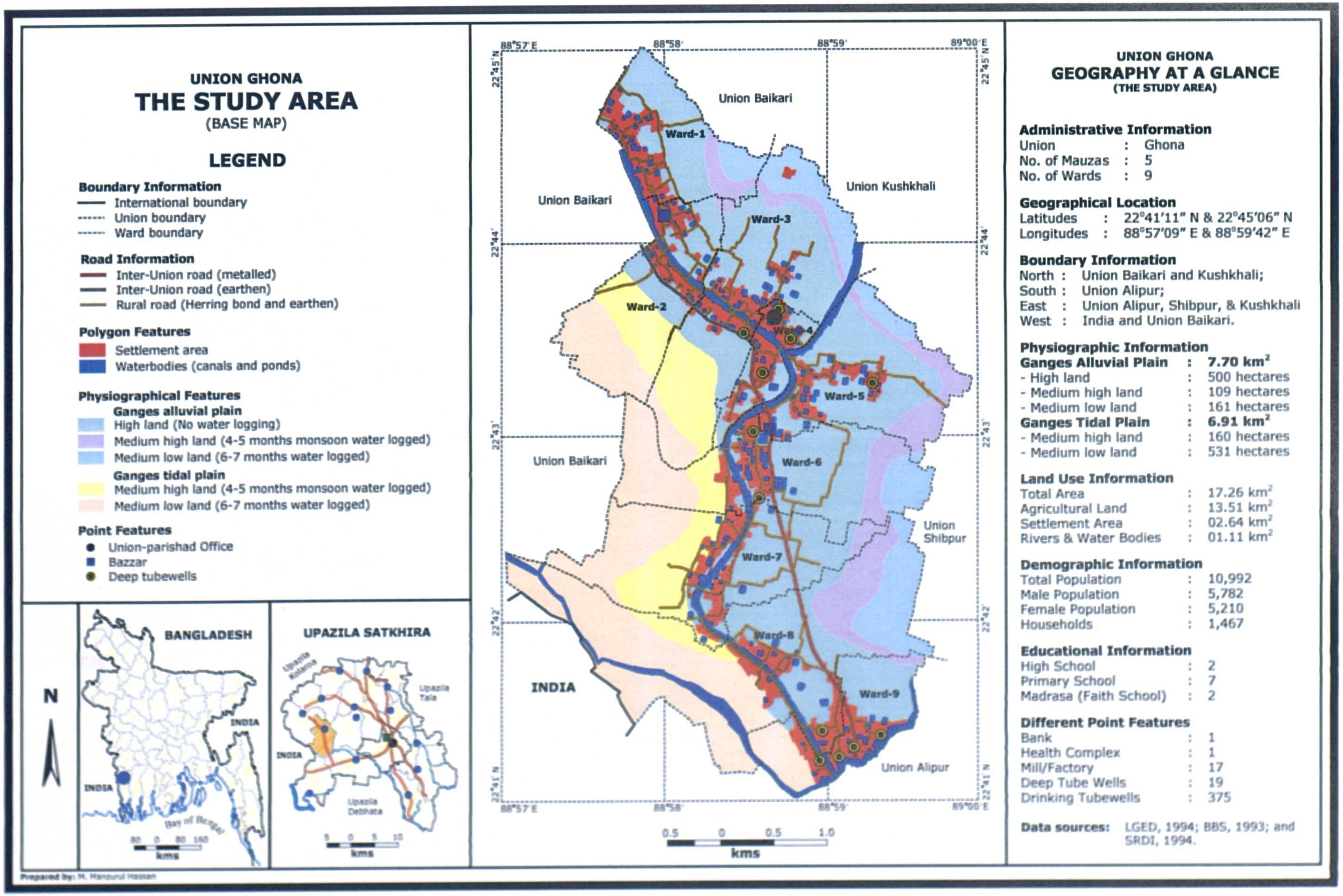
UNION GHONA
THE STUDY AREA
(BASE MAP)
LEGEND
Boundary Information
International boundary
Union boundary
Ward boundary
Road Information
Inter-Union road (metalled)
Inter-Union road (earthen)
Rural road (Herring bond and earthen)
Polygon Features
Settlement area
Waterbodies (canals and ponds)
Physiographical Features
Ganges alluvial plain
High land (No water logging)
Medium high land (4-5 months monsoon water logged)
Medium low land (6-7 months water logged)
Ganges tidal plain
Medium high land (4-5 months monsoon water logged)
Medium low land (6-7 months water logged)
Point Features
Union-parishad Office
Bazzar
Deep tubewells
N
BANGLADESH
INDIA
INDIA
UPAZILA SATKHIRA
INDIA
kms
kms
88°57′E
88°58′
88°59′
89°00′E
22°45′N
22°44′
22°43′
22°42′
22°41′N
Union Baikari
Union Baikari
Union Baikari
Union Kushkhali
Union Shibpur
Union Alipur
INDIA
Ward-1
Ward-2
Ward-3
Ward-4
Ward-5
Ward-6
Ward-7
Ward-8
Ward-9
0.5
0
0.5
1.0
kms
UNION GHONA
GEOGRAPHY AT A GLANCE
(THE STUDY AREA)
Administrative Information
Union : Ghona
No. of Mauzas : 5
No. of Wards : 9
Geographical Location
Latitudes : 22°41′11″ N & 22°45′06″ N
Longitudes : 88°57′09″ E & 88°59′42″ E
Boundary Information
North : Union Baikari and Kushkhali;
South : Union Alipur;
East : Union Alipur, Shibpur, & Kushkhali
West : India and Union Baikari.
Physiographic Information
Ganges Alluvial Plain : 7.70 km²
- High land : 500 hectares
- Medium high land : 109 hectares
- Medium low land : 161 hectares
Ganges Tidal Plain : 6.91 km²
- Medium high land : 160 hectares
- Medium low land : 531 hectares
Land Use Information
Total Area : 17.26 km²
Agricultural Land : 13.51 km²
Settlement Area : 02.64 km²
Rivers & Water Bodies : 01.11 km²
Demographic Information
Total Population : 10,992
Male Population : 5,782
Female Population : 5,210
Households : 1,467
Educational Information
High School : 2
Primary School : 7
Madrasa (Faith School) : 2
Different Point Features
Bank : 1
Health Complex : 1
Mill/Factory : 17
Deep Tube Wells : 19
Drinking Tubewells : 375
Data sources: LGED, 1994; BBS, 1993; and SRDI, 1994.

Figure 1.8

and India on the southwest (Figure 1.8). The study area consists of 5 *mauzas* and 9 Wards having the area of 17.26 Km^2 (1,726 hectres) with the population of about 11,000 with about 1,467 households in 1991 (BBS, 1993).

Detailed socio-economic data are not available for small geographical areas in Bangladesh such as that covered by the study area. However, from field observations it can be said that the study area is characterised by low levels of education and low income levels with primary economic activities relating mainly to the traditional agrarian economy. Since the study area is characterised as rural, the overall socioeconomic conditions in terms of annual average income, literacy level, occupation pattern etc are much lower than those of the Bangladesh average. That is, they are highly representative of rural Bangladesh, which has about 84% of the population. There are no private telephone users in the study area and electricity consumption is much lower than the Bangladesh average.

The area is geologically and physiographically a part of the Ganges Plain (Rashid, 1991 and SRDI, 1989). The physiography of the area mainly comprises (a) Ganges alluvial plain; (b) Ganges tidal plain; and (c) Mixed Ganges-tidal plain. The Ganges alluvial plain covers the middle part of the study area and occupies about one-third (about 750 hectares) of the study area. The northern and southern parts of the study area are characterised by the Ganges tidal plains and cover about half of the study area; while a little portion located at the southwestern border of the study area characterises the Mixed Ganges-tidal plain (Figure 1.8). The British *Khal* (canal) and the Mahmudpur *Khal* are the two main rivers flowing through the study area. The soil of the study area is slightly saline (SRDI, 1989). The study area has been dominated by irrigated agriculture for the last three decades. The heavy withdrawal of groundwater for the irrigation in the study area could be the cause of arsenic in recent times. The area has seen a rapid contamination of arsenic since 1993 and people are now at risk of arsenic toxicity.

1.11 CONCLUDING REMARKS

Tubewells are the most important source of pathogen-free drinking water since the untreated surface water in the study area is contaminated with faecal bacteria causing cholera, dysentery, diarrhoea and other water-borne diseases. The UNICEF and the World Bank (WB) suggested for the tapping of groundwater for the immediate solution of the problem of untreated surface water.

At present, the people of Bangladesh rely heavily on groundwater for drinking purposes. Groundwater development has been actively encouraged over the last few decades as a means of providing pathogen-free alternative to polluted surface water in reducing the incidence of water-borne diseases. About 97% of the population (116 million) ingest well water. Recently, this groundwater has been found to be contaminated with naturally occurring arsenic. The major arsenic problem in the study area has come from the hand-pump tubewells tapping groundwater mostly from shallow aquifers in rural areas. This arsenic concentration in Bangladesh groundwater is the greatest case of mass poisoning the world has ever experienced. In the sheer magnitude, it exceeds the Chernobyl disaster nearly 100 fold (http://phys4.harvard.edu).

Arsenic in groundwater is predominantly the result of minerals dissolving naturally from weathered rocks and soils. Some drinking water arsenic comes from contamination by human activities, e.g., it can be released by industrial or mining waste sites (http://webserver.cr.usgs.gov/trace/arsenic/). Most arsenic enters into groundwater either from natural deposits or from industrial and agricultural pollution.

This chapter has mainly focussed on the basic issues about arsenic, aims and objectives, research questions, and selection procedures of the sample study area. The next chapter will deal with the relevant literature on arsenic issues and research gaps will also be identified in the next chapter.

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CHAPTER II

LITERATURE REVIEW: CONCEPTUAL FRAMEWORKS of ARSENIC, HAZARD and RISK

CHAPTER - II

LITERATURE REVIEW: CONCEPTUAL FRAMEWORKS of ARSENIC, HAZARD and RISK

Arsenic is a common metalloid element that contaminates groundwater and is notorious for its toxicity. Inorganic arsenic dissolved in groundwater has been recognised as a 'human poison' (Matschullat *et al*, 2000). Exposure to high levels of inorganic arsenic of drinking water and food can be fatal. Daily consumption of water more than 0.01 mg/l of inorganic arsenic leads to problems with the skin, and circulatory and nervous systems (ATSDR, 2000; Bates *et al*, 1992; Hall, 2002; and WHO, 1994). As a chemical substance, arsenic is a common element in the environment. Arsenic is frequently reported to be an environmental pollutant as well as presenting a serious health concern. The greatest problems occur if arsenic poisoning is of a chronic nature, resulting in neural disorders and vital organ damage.

The materials presented in this chapter are aimed at providing an overview of arsenic issues. It is divided into six sections. The following section presents a brief summary of the conceptual frameworks of arsenic with issues concerning geological and geochemical studies. Section 2.2 presents the environmental health conditions due to chronic arsenicism. Section 2.3 discusses the literature concerning to arsenic-induced risk patterns. Section 2.4 explores aspects of social studies of arsenic and the changing pattern of social norms due to its chronic impact. Section 2.5 points out the general research gaps in arsenic issues. Finally, the last section makes some concluding remarks on the overall chapter.

2.1 CONCEPTUAL FRAMEWORKS of ARSENIC

Arsenic is found in the earth's crust at low levels (Kartinen and Martin, 1995) and is a contaminant in a wide variety of metal ores (Gochfeld, 1995). Arsenic compounds occur in various chemical states, including trivalent (inorganic), pentavalent (organic) and organoarsenical compounds (Hall, 2002). Organoarsenicals are generally considered to be nontoxic (Gochfeld, 1995); while trivalent arsenic compounds are documented human carcinogens (Hathaway *et al*, 1991) and cancers occur chronically after a long-time exposure to them (Kartinen and Martin, 1995; Goldsmith *et al*, 1972; and Harding, 1983). As a chemical substance, arsenic is of geological origin. A number of geological and geochemical surveys of varying scales have been conducted in relation to groundwater arsenic contamination regarding mainly the sources and mechanisms of arsenic release and the arsenic removal process, as well as arsenic controlling factors.

2.1.1 Arsenic in the aquatic system: geological issues

Hydrological, geological and geochemical studies provide a framework for understanding concentrations of arsenic in aquatic systems, which depend largely upon the pH and oxidation potential of water (Mariner *et al*, 1996). The most common oxidation states of arsenic in the environment are arsenite (As-III) and arsenate (As-V) (Mariner *et al*, 1996). Both organic and inorganic forms of arsenic are present in natural water systems, but inorganic arsenic dominates whereas the organic species are rarely present at concentrations above 0.001 mg/l in these water systems (Hering, 1996; Mariner *et al*, 1996; and Viraraghavan *et al*, 1994).

Arsenic (V) is a thermodynamically stable and dominating form of the inorganic arsenic species in oxic water; whereas arsenic (III) is the stable and dominating form of the inorganic arsenic species under reducing conditions (Ernest and Christoper, 1995 and O'Neill, 1990). However, arsenic (III) and arsenic (V) may occur in oxidizing and reducing conditions, respectively depending on environmental circumstances (Biswas, 2000).

Arsenic concentration is especially high in groundwater from pyrite-rich sedimentary aquifers. According to the aerobic hypothesis, due to heavy groundwater withdrawal, levels in wells drop, allowing oxygen to enter deeper water-bearing strata, thus inducing the oxidation that leaches out arsenic from pyrite ores (Acharyya, 1997; Acharyya *et al*, 1999; Appelo and Postma, 1996; and Das *et al*, 1995). Some scientists have disputed this hypothesis (Lalor *et al*, 1999; Mok and Wai, 1994; and Nickson *et al*, 2000), theorising that the lowering of the water table has no role in arsenic poisoning.

The aerobic mechanism is incompatible with the redox chemistry with water (Nickson *et al*, 2000). Arsenic produced this way would be absorbed to iron-oxyhydroxide (FeOOH), the product of oxydation (Mok and Wai, 1994 and Thornton, 1996) rather than be released to groundwater. According to the aerobic hypothesis, arsenic in groundwater is derived as a result of desorption and reductive dissolution of the surface reactive mineral phases such as hydrous ferric, aluminium and manganese oxides present as coatings (disperse phase) in aquifer sediments (Nickson *et al*, 2000 and von Brumssen, 1999).

Arsenic is naturally present in groundwater and is freed by bacteria that break down the mineral sediments. Arsenic is released when arseniferous iron-oxyhydroxides are reduced in anoxic groundwater (Bhattacharya *et al*, 1997), a process that solubilises iron and increases bicarbonate concentrations (Nickson *et al*, 2000). Sedimentary iron oxyhydroxides are known to scavenge arsenic (Mok and Wai, 1994) and, in aquifer sediments, arsenic correlates poorly with concentrations of iron (Nickson, 1997). Safiullah (1998) also confirms that a poor correlation exists between iron and arsenic. These relations strongly suggest that arsenic in groundwater beneath the Ganges plain is derived by reductive dissolution of iron oxyhydroxides in the sediment, which is known as the "oxyhydroxide reduction hypothesis" (Nickson *et al*, 2000). Welch and Lico (1998) describe various controlling factors of arsenic in groundwater and their study provides a framework for identifying processes that produce high concentrations of arsenic indicating that high arsenic concentrations in groundwater result from evaporative concentration, and dissolution relations (or redox reaction) and are affected by adsorption (Welch and Lico, 1998).

Volcanic-lithic fragments within sediments are the main source of arsenic and dissolution of this material can release arsenic to groundwater (Welch and Lico, 1998). Kondo *et al* (1999) proved that arsenic pollution does not originate artificially but occurs naturally through an elution process long ongoing on the rocks and soils by stagnant underground water. The mechanisms of arsenite and arsenate elution from the soil involved (a) anion exchange with hydroxide ion (OH^-) and (b) reductive labialisation of arsenic through the conversion of arsenate to arsenite (Kondo *et al*, 1999).

2.1.2 Arsenic analysis: geochemical issues

There are a number of different methods for measuring arsenic concentrations in water samples (Hon *et al*, 1980; Howard and Arbab-Javar, 1981; Feldman, 1979; and Pyen and Browner, 1988). Arsenic is measured mostly by Atomic Absorption Spectrometry (AAS) techniques, with samples prepared by digestion with nitric, sulphuric acid and/or perchloric acids (Dabeka and Lacroix 1987; EPA 1983 and 1994; and Hershey *et al*, 1988). The generation of hydrides which is also successfully applied in Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) (EPA 1982 and 1996a; Fengzhou *et al*, 1991; and Pyen and Browner, 1988); and successful investigation of arsenic at trace level is possible by Non-flame Atomic Spectrometry (NAS) without the use of commercial devices (Pesic and Srdanov, 1977 and Janjie *et al*, 1990/91). Other methods are employed, including spectrophotometric techniques such as Graphite Furnace Atomic Absorption Spectrometry (GFAAS) (EPA, 1994), Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (EPA, 1991, 1994 and 1998b), and X-ray Fluorescence (XRF) (Khan *et al*, 1991; Nielson and Sanders 1983; and Sbarato and Sánchez, 2001).

Arsenic causes severe poisoning in humans, and a chronic effect can appear in the body even at a low intake level. Therefore accurate measurement of arsenic magnitude has become of increasing importance. Pazirandeh *et al* (1998) measured the magnitude of arsenic in the scalp hair of people of a village in the west of Iran using neutron activation analysis. Chen and Jiang (1996) pointed out a simple and very inexpensive in-situ nebulizer/hydride generator with ICP-MS for the determination of arsenic, antimony (Sb), bismuth (Bi) and mercury (Hg) in water samples. Ding and Sturgeon (1996) pointed out a development of continuous flow electrochemical hydride generation technique coupled with in situ concentration in a graphite furnace for determination of arsenic and selenium in seawater.

Roig-Navarro *et al* (2001) conducted the simultaneous determination of arsenic species [i.e. arsenite (As-III), arsenate (As-V), monomethylarsenic acid (MMA), dimethylarsinic acid (DMA) and chromium (VI)] in drinking water by ion chromatography coupled to ICP-MS under the use of anion exchange. Vassileva *et al* (2001) also found the applicability of the same method to determine arsenic (As) and selenium (Se) species in groundwater. In addition, Grégoire and Ballinas (1997) pointed out the process of determination of arsenic from water by electrothermal vaporization ICP-MS. The XRF technique is an important analysis procedure of arsenic pollution in groundwater aquifers (Sbarato and Sánchez, 2001). By means of XRF and using an energy-dispersive spectrometer, some 50 groundwater samples from La Francia, Córdoba in Argentina, a high percentage of the analysed samples showed concentrations less than or equal to 0.05 mg/l. He *et al* (1997) have developed a rapid, simple, and sensitive fluorometric method for the determination of arsenic (III) with fluorescein as the fluorogenic reagent.

Krishna *et al* (2001) studied the functionality of an ICP-QMS and a HPLC-ICPMS procedure for speciation and determination of both As(III) and As(V) in water samples. Näykki *et al* (2001) describe the optimisation of a FI-HG technique together with AAS for the determination of arsenic, antimony and selenium in iron-based water treatment. Nielsen and Hansen (1997) determined arsenic (III) and arsenic (V) from groundwater by flow injection hydride generation atomic absorption spectrometry (FI-HG-AAS). The FI-HG-AAS is a simple procedure for the direct determination of As(III) and As(V) in water samples (Burguera *et al*, 1998; Coelho *et al*, 2002; and Samanta *et al*, 1999).

Saad and Hassanien (2001) assessed arsenic levels in hair of the nonoccupational Egyptian population, which was measured by means of hydride atomic absorption spectrophotometery. Gong *et al* (2001) studied the performance of a microwave plasma torch (MPT) discharge AES system directly coupled with HG for the determination of arsenic and antimony. Rasul *et al* (2002) describe the development of an inexpensive anodic stripping voltammetric (ASV) technique for speciation of arsenic in groundwater. The measurements are validated by atomic absorption, atomic emission and other techniques (Rasul *et al*, 2002).

Kinniburgh and Kosmus (2002) describe some analytical options in identifying arsenic concentrations in Bangladesh groundwater; while Korngold *et al* (2001) pointed out the mechanism of removal of arsenic (V) from drinking water by anion exchangers. Van Elteren *et al* (2002) describe the speciation of inorganic arsenic species [i.e. As(III) and As(V)] in some bottled mineral waters from the Radenska and Rogaška springs in Slovenia using existing speciation procedures. The hyphenated technique (HPLC-HGAFS) and a more conventional selective coprecipitation of As(III) combined with flow-injection hydride generation atomic fluorescence spectrometry (FI-HG-AFS) were used for the speciation of inorganic arsenic. Semenova *et al* (2002) have developed a software-controlled time-based multisyringe flow-injection system for total inorganic arsenic determination by HG-AFS.

Ferreira and Barros (2002) describe a simple, fast and quantitative method for determination of As(III) and total arsenic in drinking water using square wave cathodic stripping voltammetry (SWCSV) at a hanging mercury drop electrode (HMDE). The method is validated by the application of recovery and duplicate tests in the measurements of As(III) and total arsenic in natural water.

2.1.3 Remediation issues

High arsenic concentration is toxic to humans. The most common valence states of arsenic in water are arsenate, which is more prevalent in aerobic surface waters, and arsenite which is more likely to occur in anaerobic groundwater. In the pH range of 4 to 10, the predominant arsenite compound is neutral in charge, while the arsenate species are negatively charged (ATSDR, 2000). Removal efficiencies for arsenite are poor compared to the removal of arsenate by any of the technologies evaluated due to the negative charge. There are several works on arsenic removal processes. In the short term, that dissolved arsenic is often accompanied by dissolved iron provides an emergency solution to arsenic removal from arseniferous waters. Aeration of iron-rich water will precipitate iron-oxyhydroxide which will, in turn, coprecipitate some of the arsenic from solution (Pierce and Moore, 1980). Water treatment methods based upon this process have been described by Jekel (1994), Joshi and Choudhury (1996), Bhattacharaya *et al* (1997), and Safiullah (1998).

Several studies have addressed the issue of arsenic removal from natural and synthetic waters (Brandhuber and Amy, 1998; Clifford and Lin, 1991; Fox, 1989; Fox and Sorg, 1987; Gladdis and Spencer, 1979; Huxstep, 1982; and Huxstep and Sorg, 1988). Generally, these studies evaluated the ability of specific membrane systems to reduce the MCL or to remove arsenic in natural water. Apart from this, some studies concerning the membrane filtration of arsenic are important (Clifford *et al*, 1986; Chang *et al*, 1994; Hering and Elimelech, 1996; and Thompson and Chowdhury, 1993). Brandhuber and Amy (2001) describe the influences of membrane operating conditions and water quality on the rejection of arsenic by a negatively charged ultrafiltration (UF) membrane.

The EPA (1993) developed a document with contractor support, entitled "Treatment and Occurrence-Arsenic in Potable Water Supplies". This document summarised the results of pilot-scale studies examining low-level arsenic removal, from 0.05 mg/l down to 0.001 mg/l or less (EPA, 1993). Kartinen and Martin (1995), in their article "An Overview of Arsenic Removal Processes", describe the present available processes of arsenic removal technologies as well as developing economical and effective methods for removing arsenic to meet the anticipated much lower MCL. They identified three main processes: (a) Precipitation Processes (alum precipitation, iron precipitation, lime softening, and iron and manganese removal process); (b) Membrane Processes (reverse osmosis and electrodialysis); and (c) Adsorption Processes (activated alumina and ion exchange).

Ning (2002) reviews the geochemistry, natural distribution, regulation, anthropogenic sources and removal mechanisms of arsenic, pointing especially to the promise of reverse osmosis (RO) as a practical means of purification. He concludes that arsenic in commonly high oxidation states of (V) is very effectively removed by RO (Ning, 2002). Kang *et al* (2000) conducted research in order to identify the effect of solution of pH on removal efficiency of arsenic and antimony for drinking water using recently developed reverse osmosis membranes. They observed in their work that the removals of As(V) and Sb(V) are much higher than those of As(III) and Sb(III) over all investigated pH levels (pH 3-10). It is assumed that the removal of antimony in drinking water by RO membranes has a higher efficiency than that of arsenic compounds, regardless of pH changes (Kang *et al*, 2000).

Nikolaidis *et al* (1998) developed an "Arsenic Remediation Technology", which can clean arsenic-tainted water through an iron filings/sand filter. Most of the arsenic is removed from the solution. Inorganic arsenic species could also be removed from the solution through the formation of co-precipitates, mixed-precipitates and by adsorbing onto the ferric hydroxide solids (Nikolaidis *et al*, 1998). In addition, Lehimas *et al* (1998) developed a biological filtration, a cost competitive treatment used for removal of arsenic (III) indicating that "under optimised pH, temperature and oxygenation conditions, biological filteration allows simultaneous elimination of arsenic (III) and iron".

Viraraghavan *et al* (1994) reviewed some treatment technologies of arsenic from drinking water. In their article, they showed the relative merits and demerits of some technological options of groundwater arsenic treatment. Sato *et al* (2002) examined the performance of the nanofiltration (NF) membrane method in reducing health risks of arsenic-contaminated drinking water. They observed that the NF membrane could remove over 95% of Arsenic (V) and over 75% of Arsenic (III) without any chemical additives (Sato *et al*, 2002). Oh *et al* (2000) conducted research on the applicability of the nanofiltration (NF) membrane process coupled with a bicycle pumping system for the treatment of arsenic-contaminated drinking water in rural Bangladesh where electricity supply is not efficient or feasible; while Vrijenhoek and Waypa (2000) investigated the removal of arsenic from water by a 'loose' nanofiltration (NF) membrane.

Cheng *et al* (1994) described the enhanced coagulation procedure for removal of arsenic from groundwater; while Edwards (1994) pointed out arsenic removal from drinking water during coagulation and Fe-Mn oxidation. Gregor (2001) describes the functionality of conventional aluminium-based coagulation treatment processes for removal of arsenic from drinking-water. The ability of this water treatment process to achieve the maximum acceptable concentration for arsenic in drinking water is dependent on the concentrations of As(III) in source water (Gregor, 2001). Zaw and Emett (2002) describe the removal of arsenic from groundwater using advanced oxidation processes, which utilise ultraviolet light and a photo absorber that is being used successfully to remove arsenic by precipitation or ion exchange methods; while Xu *et al* (2002) describe adsorption and removal of arsenic (V) from drinking water by aluminium-loaded Shirasu-zeolite.

Katsoyiannis and Zouboulis (2002) pointed to the possible removal of arsenic from contaminated water sources by sorption onto iron-oxide-coated polymeric materials (polystyrene and polyHIPE) by coating their surface with adsorptive filtration. This method showed its capability to remove arsenic from contaminated water below 0.01 mg/l (Katsoyiannis and Zouboulis, 2002). Flocculation and microfiltration techniques are also important in removing arsenic from drinking water. Han *et al* (2002) comment that flocculation prior to microfiltration leads to significant arsenic removal in permeates. Further, the addition of small amounts of cationic polymeric flocculants lead to significantly improved permeate fluxes during microfiltration. The residual turbidity, after flocculation and microfiltration, may be used as a guide to the level of arsenic removal (Han *et al*, 2002).

An appropriate batch-mixed treatment has been developed by Ramaswami *et al* (2001) with zero-valent iron as a point-of-use technology for arsenic removal from groundwater. Batch tests with iron showed that high arsenic removal (>93%) can be achieved from highly arsenated water (2.0 mg/l) over a short contact time of 0.5-3.0 hours (Ramaswami *et al*, 2001). Krishna *et al* (2001) studied the development of an arsenic remediation approach using Fenton's reagent (H_2O_2 and Fe(II)) followed by passage through zero valent iron for the removal of arsenic from drinking water.

Yokota *et al* (2001) describe groundwater arsenic contamination and the water purification system using pond water in Samta village of Jessore district in Bangladesh. About 90% of tubewells in this village had arsenic concentrations above the Bangladesh standard limit of 0.05 mg/l. They analysed the functionality of a local pond sand filter (PSF) system, which purifies pond water. They found that the installed PSF system in Samta produces good quality treated water. Meng *et al* (2001) evaluate the effectiveness of a household filtration process on the removal of arsenic from Bangladesh groundwater by ferric hydroxides. The household filtration process included co-precipitation of arsenic by adding a packet (approximately 2 g) of ferric and hypochlorite salts to 20 litres of well-water and subsequent filtration of water through a bucket sand filter. Experimental results proved that this household treatment process removes arsenic from approximately 0.300 mg/l in the well-water to a level of less than 0.05 mg/l (Meng *et al*, 2002).

Although various methods have been adopted to remove inorganic species of arsenic from drinking water, little emphasis has been given to the removal of organic species of arsenic. In a study from Saskatchewan, Canada, Thirunavukkarasu *et al* (2001) pointed out from conducted column studies using manganese greensand (MGS), iron oxide-coated sand (IOCS-1 and IOCS-2) and ion exchange resin in Fe^{3+} form, to examine the removal of organic arsenic (dimethylarsinate) spiked to required concentrations in tap water.

2.2 ENVIRONMENTAL HEALTH STUDIES

Ingestion of arsenic has long been associated with toxic effects, producing marked impacts on human health. Effects range from acute lethality to chronic effects. Arsenic contamination of the environment has received much attention due to toxicological evidence of its potential human health hazards, e.g., skin diseases including an enhanced skin cancer risk potential, liver disturbances, heart diseases etc, even at lower levels of exposure (Abernathy *et al*, 1997). The most deceptive and dangerous aspect *of arsenic toxicity is its very slow and* insidious development (Table 2.1).

Arsenic toxicity starts in the human body when exposed to an excessive quantity of arsenic. It is estimated that it takes about 5-15 years to develop chronic arsenicosis symptoms and, over time, the symptoms can become more pronounced and in some cases, internal organs including the liver, kidneys and lungs can be affected (WHO, 1996). In the most severe cases, cancer can occur in the skin and internal organs, and limbs can be affected by gangrene (UNICEF, 2000). The period differs from patient to patient depending on the amount of arsenic ingested, the nutritional status of the person, the immunity level of the individual and the total time of arsenic ingestion (UNICEF, 2000).

There are many case reports of death due to ingestion of high doses of arsenic (ATSDR, 2000). Based on a review of clinical reports, Vallee *et al* (1960) estimated the minimum lethal dose to be about 70–180 mg (about 1-3 mg/kg). Death due to chronic arsenic exposure has been reported at lower concentrations. Five children between the ages of 2 and 7 years died from late sequelae of chronic arsenic poisoning after drinking contaminated water throughout their lives at estimated average doses of 0.05–0.1 mg As/kg/day (Zaldivar and Guillier 1977). A 22-year-old man with arsenical dermatosis died from chronic arsenic-related effects after a lifetime exposure to an estimated average dose of 0.014 mg As/kg/day in drinking water (Zaldivar *et al*, 1981).

Table 2.1
Effects of chronic arsenic exposure to humans

System	Effects
Skin	Skin lesions
Cardiovascular	Blackfoot disease
Nervous	Peripheral neuropathy, encephalopathy
Hepatic	Hepatomegaly, cirrhosis, altered heme metabolism
Haematological	Bone marrow depression
Endocrine	Diabetes
Renal	Proximal tubule degeneration, papillary and cortical necrosis

Source: Hughes, 2002.

Large numbers of people in Taiwan, Chile, Mexico, India and Bangladesh have been chronically poisoned from naturally occurring arsenic in groundwater. This is due to trivalent arsenic compounds that are human carcinogens, causing tracheal and bronchogenic carcinomas, hepatic angiosarcomas (Bates *et al*, 1992), and various skin cancers, such as intraepidermal carcinomas (Bowen's disease), basal cell carcinomas (BCC), squamous cell carcinomas (SCC), 'combined' forms of skin cancer (ATSDR, 2000 and Hall, 2002) and myelogenous leukomia (Kjeldsberg and Ward, 1972). Internal cancers of the lung, liver, bladder, and kidney have also been associated with chronic ingestion (Bates *et al*, 1992; Cuzick *et al*, 1992; and Chiou *et al*, 1995).

Skin pigmentation changes, palmar and plantar hyperkeratoses, gastrointestinal symptoms, anaemia, various skin cancers, and liver disease are common in chronically exposed persons (ATSDR, 1990; Guha Mazumder *et al*, 1992; Subramanian and Kosnett, 1998; and Ahsan *et al*, 2000). Noncirrhotic portal hypertension with bleeding oesophageal varices, splenomegaly, hypersplenism, and typical skin manifestations have been found in patients treated with Fowler's solution (Nevens *et al*, 1990).

A metallic taste in the mouth and gastrointestinal disturbances may be present. Bone marrow depression with anemia, leukopenia, or pancytopenia is common (ATSDR, 1990). Gangrene of feet (blackfoot disease) has been associated with chronic ingestion in Taiwan; Raynaud's phenomenon and acrocyanosis may also occur (ATSDR, 1990). Toxic delirium and encephalopathy can be present (Morton and Caron, 1989). Peripheral neuropathy is common in persons chronically exposed to arsenic-contaminated drinking water (ATSDR, 2000 and Guha Mazumder *et al*, 1992). Table 2.2 shows the levels of significant exposure to inorganic arsenic ingestion and its impacts on human health.

2.2.1 Arsenic and non-carcinogenic effects

Long-term exposure to inorganic arsenic in drinking water is associated with non-carcinogenic as well as non-malignant health effects in the forms of darkening of skin and the appearance of small 'corns' or 'warts' on palms and soles. Apart from this, diabetes, peripheral neuropathy, cardiovascular diseases, ischemic heart disease, bronchitis etc are the results of non-malignant effects of low-dose of chronic arsenic ingestion (Abernathy *et al*, 1999). A few years of contaminated exposure to low levels of inorganic arsenicals causes different skin ailments and the apparent symptoms of arsenicosis[1] are manifested in the form of hypopigmentation (white spots), hyperpigmentation (dark spots), collectively called melanosis[2] by some physicians, keratosis[3] and leuko-melanosis[4] mainly. A low level of exposure to inorganic arsenic causes chronic toxicity in the body.

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[1] Arsenicosis is a disease caused by drinking arsenic-contaminated water that can lead to a very painful death.

[2] Melanosis means the darkening of skin in a diffuse or spotted form due to the deposition of black pigment and occurs on the palms, legs, soles of the, trunk, gums, tongue, lips and the whole body. It is the earliest symptom of arsenicosis.

[3] Keratosis means the thickening and hardening (roughness) of palms and soles. Rough and dry skin often with spotted keratosis (palpable nodules) in the dorsum of hands, feet and legs are the symptoms of moderately severe toxicity. More generally, keratosis is any skin disorder attended by horny growths. The causes and lesion characteristics of keratotic skin disorders are varied.

[4] Leuko-melanosis means the alternate darkened light spots.

Table 2.2
Levels of significant exposure to inorganic arsenic ingestion

Exposure (years)	Systems	NOEAL* (mg/kg/day)	LOEAL* (mg/kg/day)		Chemical Form	References
			Less serious (mg/kg/day)	**Serious** (mg/kg/day)		
Death						
5	-	-	-	1 (Increased death)	Arsenic (+3)	Tsuda *et al*, 1995
12	-	-	-	0.24 (Death in 4/208)	-	Zaldivar, 1974.
1-39	-	-	-	0.13 (Death in 5/337)	-	Zaldivar and Guillier, 1977
Systemic						
3-7	Dermal	-	0.0008 (Hyperkeratosis, hyperpigmentation)	-	-	ATSDR, 2000
11-15	Dermal	-	0.01 (Hyperpigmentation, hyperkeratosis)	-	-	Borgono *et al*, 1980
Continuous	Dermal	0.0004	0.022 (Pigmentation changes, hyperkeratosis)	-	-	ATSDR, 2000
3-7	Cardio	-	-	0.11 (Blackfoot disease)	-	Foy *et al*, 1992
1-39	Cardio	-	-	0.06 (Arterial thickening, Raynaud's disease)	-	Zaldivar and Guillier, 1977
Continuous	Cardio	-	-	0.064 (Blackfoot disease)	-	Chen *et al*, 1988
2-7	Gastro	-	0.024 (Chronic diarrhoea)	-	-	ATSDR, 2000
5-15	Gastro	-	0.05 (Abdominal pain)	-	-	Huang *et al*, 1985
Continuous	Gastro	0.0004	0.022 (Gastrointestinal irritation, diarrhoea)	-	Arsenic (+5)	Cebrian *et al*, 1983
1-11	Hepatic	-	0.02 (Hepatomegaly)	-	-	Chakraborty and Saha, 1987
12	Hepatic	-	-	0.02 (Arterial thickening, cirrhotic changes)	-	ATSDR, 2000
1-20	Hemato	-	0.007 (Anemia)	-	-	ATSDR, 2000
Immunological						
2-7	-	-	0.024 (Splenomegaly)	-	-	Zaldivar, 1974
1-11	-	-	0.020 (Spleen palpable in 3%)	-	-	Chakraborti and Saha, 1987
12	-	-	-	0.02 (Arterial thickening in spleen)	-	Rosenberg, 1974
Neurological						
3-7	-	0.0008	-	0.11 (Weakness, anorexia)	-	Foy *et al*, 1992
1-20	-	-	0.007 (Tingling of hands and feet)	-	-	Guha Mazumder *et al*, 1988
Continuous	-	0.0007	0.019 (Electromyographic abnormalities)	0.04 (Functional denervation)	-	Hindmarsh *et al*, 1977
Cancer						
>10	-	-	-	0.001 (Liver, lung, bladder and kidney cancer risk)	-	Chen *et al*, 1992
Continuous	-	-	-	0.064 (Bladder, lung and liver cancers)	-	Chen *et al*, 1986

* **NOEAL** – No observable adverse health effect; and **LOEAL** – Lowest observable adverse health effect.

Dermal effects. Long-term exposure to low levels of arsenic causes different types of skin lesions that have been identified from the testing of urine samples. Symptoms of chronic arsenic intoxication include general pigmentation or focal 'raindrop' pigmentation of the skin or hyperpigmentation on the mucosa as well as diffused pigmentation and the appreance of hyperkeratosis of the palms of hands and soles of feet, face, neck and back (ATSDR, 2000; Col *et al*, 1999; Cebrian *et al*, 1983; Franzblau and Lilis 1989; Hall, 2002; Haupert *et al*, 1996; Huang *et al*, 1985; Saha and Poddar 1986; Tseng *et al*, 1968; and Wong *et al*, 1998a).

In examining and interviewing arsenic contaminated patients in Bangladesh, skin lesions have been identified in terms of keratosis, hyperpigmentation, or hypopigmentation (Tondel *et al*, 1999). Jaafar *et al* (1993) also observed arsenical skin lesions of keratosis and hyperpigmentation by examining the patients and measuring arsenic magnitudes in their drinking water in Malaysia. In a study from West Bengal, India, it was identified that among those who are consuming water with <0.05 mg/l of arsenic, keratosis was common and those who were consuming water containing >0.08 mg/l of arsenic, hyperpigmentation appeared in their bodies (Guha Mazumder *et al*, 1998a). Calculation by dose per body weight (dose-index) shows that there is a higher prevalence rate of arsenic skin lesions (keratosis and hyperpigmentation) in males than females, with a clear dose-response relationship (Guha Mazumder *et al*, 1998b and Tondel *et al*, 1999). Disturbances of respiratory and digestive systems have also been identified as the first symptoms of low level chronic arsenic poisoning.

It has been found from a study in West Bengal that risk of arsenic-associated skin lesions or keratosis are possible with the low levels of arsenic-contamination (<0.05 mg/l) in drinking-water (Das *et al*, 1996). Numerous studies in humans have reported dermal effects at chronic dose levels ranging from 0.01 to 0.1 mg As/kg/day (Borgono and Greiber 1972; Chakraborty and Saha 1987; Foy *et al*, 1992; and Guha Mazumder *et al*, 1992). Dermal lesions have also been noted in some other studies (Ahmad *et al*, 1997; Bates *et al*, 1992; Borgono *et al*, 1977; Bickley and Papa 1989; and Wong *et al*, 1998b).

Diabetes mellitus. Diabetes mellitus has also been linked with drinking water arsenic exposure. It is suggested from a study that skin lesions and diabetes mellitus (glucosuria) are largely the effects of exposure to arsenic (Rahman and Axelson, 1995 and Rahman *et al*, 1999a).

There are several epidemiological reports linking diabetes mellitus with arsenic exposure from environmental and occupational sources (Tseng *et al*, 2002). In Taiwan, the prevalence and mortality rates of diabetes mellitus have been reported to be higher among the population of areas where blackfoot disease (a peripheral vascular disease resulting in gangrene of the lower extremities) is endemic. Testing the oral glucose tolerance and examining 891 adults residing in villages of blackfoot disease endemic area, Lai *et al* (1994), found an association between ingested inorganic arsenic and prevalence of diabetes mellitus. Residents in the blackfoot disease endemic areas had a two-fold increase in the prevalence of diabetes mellitus (after adjustment for age and sex) when compared to residents in Taipei and the entire Taiwan population (Lai *et al*, 1994). Positive associations between arsenic exposure and diabetes mellitus have also been demonstrated in other studies from Taiwan (Tsai *et al*, 1999 and Tseng *et al*, 2002).

Determining the history of symptoms, a positive association with diabetes has also been found in Bangladesh, having a statistical significance between diabetes mellitus and exposure to arsenic (Abernathy *et al*, 1999 and Rahman *et al*, 1998). Rahman *et al* (1998) used the presence of keratosis as an indicator of arsenic exposure and showed elevated risks for diabetes in those exposed to arsenic in their drinking water (prevalence ratio = 5.9). On the contrary, Lewis *et al* (1999) failed to find a significant excess in the number of deaths from diabetes in males and females exposed to elevated levels of arsenic in drinking water.

Neurological effects. It is evident that acute arsenic poisoning causes neurological effects, especially in the peripheral nervous system (Armstrong *et al*, 1984; Civantos *et al*, 1995; Fincher and Koerker 1987; Levin-Scherz *et al*, 1987; and Quatrehomme *et al*, 1992), but a large number of epidemiological studies and case reports indicate that ingestion of long-term inorganic arsenic can cause various neurological symptoms (Foy *et al*, 1992; Hindmarsh *et al*, 1977; Huang *et al*, 1985; and Szuler *et al*, 1979). Repeated exposures to lower levels (0.03–0.1 mg As/kg/day) are typically characterised by a symmetrical peripheral neuropathy (Franzblau and Lilis 1989; and Szuler *et al*, 1979). This neuropathy usually begins as a numbness in the hands and feet, but later may develop into a painful 'pins and needles' sensation (Abernathy, 2001).

Hindmarsh *et al* (1977) reported a positive association between electromyography (EMG) abnormalities and arsenic levels in drinking water and hair samples in residents of Nova Scotia, Canada. Among those using water with more than 1 mg/l of arsenic, the frequency of EMG abnormalities was 50% (Hindmarsh *et al*, 1977). Neurological effects are not generally found in populations chronically exposed to doses of 0.006 mg As/kg/day or less (Harrington *et al*, 1978; Hindmarsh *et al*, 1977; and Southwick *et al*, 1982), but fatigue, headache, dizziness, insomnia, etc were among the symptoms reported at 0.005 mg As/kg/day in a study of 31,141 inhabitants from 77 villages in Xinjiang, China (Lianfang and Jianzhong 1994).

Vascular effects. Exposure to arsenic has been linked to various vascular alterations affecting both the large and small blood vessels. Several studies in Taiwan have demonstrated an association between arsenic ingestion and vascular diseases. Much of the early work on arsenic and vascular disease focused on effects in small vessels (i.e. blackfoot disease and other peripheral vascular diseases), while later research has been directed primarily at effects in larger vessels (cardiovascular and cerebrovascular diseases) (Chen *et al*, 1988b; Chiou *et al*, 1997; Jensen and Hansen, 1998; and Tseng *et al*, 1996). Some work has also been carried out on the possible link between arsenic exposure and hypertension, a known vascular disease risk-factor having the systolic blood pressure of 160 mmHg or greater in combination with a diastolic blood pressure of 95 mmHg or greater (Chen *et al*, 1995a and Rahman *et al*, 1999b).

Disturbances of circulatory systems mainly appear at the later stages of arsenic poisoning as an arteriosclerotic change. Investigating the ecological relationship between arsenic exposure and mortality from circulatory disease in the United States from 1968 to 1984, Engel and Smith (1994) suggest that the Standard Mortality Ratios (SMRs) for congenital anomalies of heart and circulatory system tended to be high due to the chronic exposure to arsenic.

A number of studies indicate that low-level chronic arsenic exposures lead to a serious effect on the cardiovascular system (Cullen *et al*, 1995; Lee *et al*, 2002; and Little *et al*, 1990). Studies in Taiwan involving blackfoot disease patients have shown significant associations, including dose-response relationships between arsenic concentrations in well-water and death rates from cardiovascular disease (Chen *et al*, 1996; Tsai *et al*, 1999; and Wu *et al*, 1989).

Engel and Smith (1994) carried out a study on ecological mortality in which mortality due to cardiovascular diseases in 30 US counties was compared to the expected numbers of deaths generated by US mortality rates. The results indicated excess mortality rates for diseases of the arteries and anomalies of the circulatory system. The standard mortality ratios (SMRs) for these diseases were elevated for areas with arsenic concentrations of >0.002 mg/l (Engel and Smith, 1994). Lewis *et al* (1999) examined several mortality outcomes among a cohort of individuals from Utah, USA. They observed a significant excess of deaths for cardiovascular diseases among males (SMR=2.20) and among females (SMR=1.73) (Lewis *et al*, 1999). In contrast, some studies of chronic human arsenic exposure report no cardiovascular effects (Guha Mazumder *et al*, 1998a).

Arsenic has been linked to the development of blackfoot disease and peripheral artery disease. The condition is characterised by an insidious onset of coldness and numbness in the feet, followed by ulceration, black discoloration and subsequently dry gangrene of the affected parts. Studies from Taiwan have clearly demonstrated that exposure to arsenic via drinking water is associated with blackfoot disease, with significant dose-response relationships (WHO, 2001). The average drinking water levels of arsenic range from 0.17 to 0.80

mg/l in the blackfoot disease endemic area of Taiwan where (Tseng, 1977), corresponding to doses of about 0.014–0.065 mg As/kg/day (Abernathy *et al*, 1999).

In a cohort of 789 blackfoot disease patients followed for 15 years, Chen *et al* (1988b) reported that there was a significant increase in the number of deaths from peripheral vascular diseases among residents of the blackfoot disease endemic area. In addition, examining 582 adults from the blackfoot disease endemic villages of Taiwan and using multiple logistic regression analysis, Tseng *et al* (1996) showed a close relationship between long-term arsenic exposure and the prevalence of peripheral vascular disease. An increased risk of peripheral vascular disease was found in a study of subjects residing in 42 villages located in the blackfoot disease endemic area of Taiwan (Wu *et al*, 1989).

Arsenic exposure in Taiwan has also been associated with an increased incidence of cerebrovascular disease (Chiou *et al*, 1997; Wu *et al*, 1989; and Tsai *et al*, 1999) and ischemic heart disease (Chen *et al*, 1996; Hsueh *et al*, 1998). Chiou *et al* (1997) conclude that long-term exposure to inorganic arsenic is associated with an increased prevalence of cerebrovascular disease, especially cerebral infarction. There is an association between chronic arsenic exposure and ischemic heart disease (ISHD). Arsenic related ISHD has a pathogenic mechanism, which is not similar from that of ISHD unrelated to long-term exposure to arsenic (Hsueh *et al*, 1998). The dose-response relationship between ISHD and long-term arsenic exposure has been shown by Chen *et al* (1996).

Chronic exposure to inorganic arsenic induces hypertension in humans. Examining a total of 1,481 subjects exposed to arsenic-contaminated drinking water and 114 unexposed subjects aging 30 years or more from Bangladesh, Rahman *et al* (1999b) showed a significant dose-response relationship between arsenic exposure and increased blood pressure. Chen *et al* (1995b) studied a total of 382 men and 516 women residing in villages from the blackfoot disease endemic areas in Taiwan and proved the prevalence of hypertension as the long-term effect of arseniasis describing "the higher the cumulative long-term arsenic exposure, the higher the prevalence of hypertension". The authors showed that arsenic-exposed residents had a 1.5-fold increase in age-sex adjusted prevalence of hypertension compared with residents in non-endemic areas (Chen *et al*, 1995a). A study in Utah, USA found an excess of mortality from hypertensive heart disease but there were only a small number of deaths (WHO, 2001). Guha Mazumder and Das Gupta (1991) suggest a relationship between arsenic exposure and non-cirrhotic portal hypertension. Lewis *et al* (1999) also identified hypertensive heart disease as related to chronic arseniasism.

It should be noted that, although hypertension is not a very important cause of death itself, it is a major risk factor for other vascular diseases. Some of the Taiwanese studies have shown an elevated risk of death from cerebrovascular disease, but studies from other countries provide only very limited support for the Taiwanese findings (WHO, 2001). Studies in Chile indicate that ingestion of 0.6-0.8 mg/l of arsenic in drinking water (corresponding to doses of 0.02-0.06 mg As/kg/day, depending on age) increases the incidence of Raynaud's disease and of cyanosis of fingers and toes (Borgono and Greiber, 1972; Zaldivar, 1977; and Zaldivar and Guillier, 1977). Cardiac failure, arterial hypertension, myocardial necrosis, and thrombosis have been observed in children who died from chronic arsenic ingestion as well as adults chronically exposed to arsenic (Zaldivar 1974). Likewise, thickening and vascular occlusion of blood vessels were noted in adults who drank arsenic-contaminated drinking water (Zaldivar and Guillier 1977).

Hepatic manifestation. A number of studies in humans exposed to inorganic arsenic have noted symptoms of hepatic injury. Clinical examination often reveals that the liver is swollen and tender (Zaldivar 1974), and the analysis of blood sometimes shows elevated levels of hepatic enzymes (Armstrong *et al*, 1984; and Franzblau and Lilis 1989). These effects are most often observed after repeated exposure to doses of 0.01–0.1 mg As/kg/day, although doses as low as 0.006 mg As/kg/day have been reported to be effective with chronic exposure

(Chakraborty and Saha 1987; Guha Mazumder *et al*, 1998a; and Hernandez-Zavala *et al*, 1998).

On the basis of cohort follow-up studies in patients who consumed arsenic-contaminated drinking water for one to 15 years with clinical and laboratory examinations, Santra *et al* (1999) identified the hepatotoxic action of chronic exposure of arsenic-contaminated water. Many cases of hepatomegaly, splenomegaly and liver diseases were the established effects of chronic arsenicosis (Santra *et al*, 1999); while Hernandez-Zavala *et al* (1998) found the same effects in Mexico. Besides, non-cirrhotic portal fibrosis (NCPF) has been identified as the predominant lesion in liver histology as the result of chronic arsenic toxicity (Santra *et al*, 1999 and Guha Mazumder *et al*, 1998a).

Hematological and reproductive effects. Anaemia and leukopenia are common effects of arsenic poisoning in humans at doses of 0.05 mg As/kg/day or more (Guha Mazumder *et al*, 1998a and Tay and Seah, 1975). These effects may be due to both a direct cytotoxic or hemolytic effect on the blood cells and a suppression of erythropoiesis (Armstrong *et al*, 1984; Fincher and Koerker 1987; and Goldsmith and From 1986). However, hematological effects are not observed in all cases of arsenic exposure (Harrington *et al*, 1978; Huang *et al*, 1985; and Southwick *et al*, 1982).

A number of studies have showed that arsenic has also been linked to adverse reproductive outcomes in terms of increased foetal, neonatal and postnatal mortalities, and elevations in low birth weights, spontaneous abortions, stillbirths, pre-eclampsia and congenital malformations (Abernathy, 2001). In contrast, some studies have produced conflicting results. Zierler *et al* (1988) found no evidence of an increased frequency of congenital heart disease in infants born to women consuming drinking water containing arsenic levels of 0.0008-0.022 mg/l.

Gastrointestinal and respiratory effects. Clinical signs of gastrointestinal irritation, including nausea, vomiting, diarrhoea, and abdominal pain are observed in essentially all cases of chronic exposures to arsenic of about 0.01 mg As/kg/day (Franzblau and Lilis, 1989; Guha Mazumder *et al*, 1998a; Harrington *et al*, 1978; Haupert *et al*, 1996; and Huang *et al*, 1985). In addition, some studies have reported minor respiratory symptoms, such as cough, sputum, rhinorrhea, and sore throat in people with chronic exposure to 0.03–0.05 mg As/kg/day inorganic arsenic (Ahmad *et al*, 1997).

2.2.2 Arsenic and carcinogenic effects

Arsenic has been associated with increased incidence of human cancer in certain highly exposed populations through the natural contamination of drinking water sources. Several lines of evidence indicate that the genotoxic effects of arsenic may lead to carcinogenesis, which established arsenic as a carcinogen (a substance that can cause cancer) and the long-term exposure to inorganic arsenicals leads to cancers (Brown and Chen, 1995; Chatterjee and Mukherjee, 1999; Jaafar *et al*, 1993; Hsueh *et al*, 1995; Gou and Lu, 1994; Mushak and Croeetti, 1995; Tseng *et al*, 1995 and Woollons and Russel-Jones, 1998).

Tsai *et al* (1998) identified relationships between arsenic and malignant tumours in a study of a blackfoot disease endemic area in Taiwan, indicating that malignant cancers are mainly due to the long-term ingestion of arsenic. The decreasing trend of mortality incidence of arsenic-related cancers due to the improvement of drinking water supply in blackfoot disease endemic communities confirmed the association. Over the past 20-30 years, research effort has also focused on the likely relationship between various types of cancers and exposure to arsenic through the consumption of drinking water. Much of this type of work has centred on Taiwan, but there are reports of elevated cancer risks at multiple sites (notably lung, skin, bladder, kidney and liver) from other parts of the world including Argentina, China and Chile where subsets of the population are exposed to arsenic-contaminated drinking water (Abernathy, 2001).

Skin cancer. There is convincing evidence from a large number of epidemiological studies and case reports that ingestion of inorganic arsenic from drinking water increases the risk of developing skin cancer (Alain *et al*, 1993; Bickley and Papa 1989; Haupert *et al*, 1996; Hsueh *et al*, 1995; Lüchtrath 1983; Morris *et al*, 1974; Tsai *et al*, 1998; Tseng 1977; Tseng *et al*, 1968; and Zaldivar *et al*, 1981). Induction of cancer by inorganic arsenic occurs inconsistently between species and between routes of exposure (Byrd *et al*, 1996). Evidence from studies of West Bengal, India, shows that malignant neoplasms like Bowen's disease with regard to skin cancers are the resultant effect of chronic exposure to arsenic (Saha *et al*, 1999). Bowen's disease may appear as the symptoms of long-term exposure to chronic arsenicism (Col *et al*, 1999). Moreover, Foy *et al* (1992) from a study of Thailand investigated the relationships between arsenic exposure and Bowen's carcinoma.

Hsueh *et al* (1995) conducted a cross-sectional study to evaluate the prevalence of arsenic-induced skin cancer among residents in Taiwanese villages exposed to inorganic arsenic in drinking water (0-0.93 mg/l). A dose-response increase in skin cancer was associated with arsenic. Lesions commonly observed are multiple BCC and multiple SCC (ATSDR, 2000 and EPA 1988). In most cases, skin cancer develops only after prolonged exposure, but several studies have reported skin cancer in people exposed for less than one year (Reymann *et al*, 1978; Wagner *et al*, 1979). In contrast, several epidemiological studies performed in the United States have not detected an increased frequency of skin cancer in small populations consuming water containing arsenic at levels of around 0.1–0.2 mg/l (Goldsmith *et al*, 1972; Harrington *et al*, 1978; Morton *et al*, 1976; and Southwick *et al*, 1982).

Internal cancers. In addition to the risk of skin cancer including BCC and SCC, there is an increased risk of some internal malignancies (ATSDR, 2000; Col *et al*, 1999 and Lewis *et al*, 1999). Numerous epidemiological studies from Taiwan, Chile and Argentina show consistently high mortality risks from lung, bladder and kidney cancers among populations exposed to arsenic through drinking water (Abernathy *et al*, 1999; Bates *et al*, 1992; Smith *et al*, 1992; and WHO, 2001). It is reported from various reports and published articles that after a latency of 20-30 years, internal cancers, particularly of the bladder and lung, could appear (http://phys4.harvard.edu).

Early reports of serious arsenic contamination of groundwater and its impacts on skin and internal cancers came from Taiwan about four decades ago. Various studies in Taiwan have found dose-response relationships between arsenic ingestion from drinking water and cancers of the skin, bladder, lung, kidney and liver (Brown and Chen, 1995; Engel and Smith, 1994; Hopenhayn-Rich *et al*, 1998; Lin *et al*, 1995; Lin *et al*, 1998; Tsai *et al*, 1998; and Yu *et al*, 1998). Moreover, chronic exposure to arsenic causes rectal cancer as well (Tsai *et al*, 1999).

Arsenic is genotoxic to bladder cells (Moore *et al*, 1997a) and ingesting inorganic arsenic is an established cause of bladder malignancies (Karagas *et al*, 1998 and Smith *et al*, 1993). Epidemiological studies performed in Taiwan, Mexico, Argentina and Chile have found a dose-response relationship between ingestion of inorganic arsenic from drinking water and bladder cancer (Chiang *et al*, 1993). In addition, Hopenhayn-Rich *et al* (1996a) investigated the higher bladder cancer standardised mortality ratios (SMRs) due to the documented arsenic exposure between 1986 and 1991 in 26 counties of Cordoba Province, Argentina. The mortality records for all deaths occurring between 1949 and 1959 in areas with high arsenic levels in drinking water (weighted average approximately 0.6 mg/l) were compared with cause-specific mortality rates from the entire province. Thirty five percent of all cancer deaths were related to respiratory organs (Bergoglio, 1964). The strongest epidemiological association was found between arsenic ingestion and the internal and bladder cancers. Hopenhayn-Rich *et al* (1996a) also observed that bladder cancer SMRs were consistently higher in counties with documented arsenic exposure. In addition, arsenic-contaminated drinking water induces genetic damage to bladder cells (Brown and Beck, 1996; Orellana, 2001; Moore *et al*, 1997a and Smith *et al*, 1993).

Epidemiological studies suggest that long-term ingestion of arsenic contaminated water causes more fatal internal cancers (Chiou *et al*, 1995; Chen *et al*, 1992 and Morris, 1995) with the highest for bladder cancer as well as inducing genetic damage to bladder cells (Moore *et al*, 1997a). Cuzick *et al* (1992) describe the highest risk for bladder cancer as the effect of chronic arsenic exposure measured from a cohort of 478 patients in England during 1945-1980; while Kurttio *et al* (1999) find contradictory evidence in the association of low level arsenic exposure with the risk of bladder and kidney cancers in a study from Finland. Their study population comprised a group of 61 bladder cancer cases, 49 kidney cancer cases and 275 control subjects; they reconstructed exposure history from questionnaire data on residence and from measurements of arsenic in well-water made in 1996 (range <0.0005 to 0.064 mg/l; median 0.00014 mg/l) and found no association with kidney cancer (Kurttio *et al*, 1999).

Guo *et al* (1997) identified associations for urinary cancers of various cell types and arsenic ingestion indicating that the "carcinogenicity of arsenic may be cell type specific". Tsuda *et al* (1995) also indicate a high mortality rate for urinary tract cancer as the long-term effect of exposure to ingested arsenic with a cohort study followed for 33 years in Japan. They also described that the exposure for 5 years to a high dose of arsenic (>0.1 mg/l) can cause skin signs of chronic arsenicism for subsequent cancer development (Tsuda *el al*, 1995). Buchet and Lison (1998) investigated the dose-response relationship for lung carcinoma and other cancers at low doses of arsenic, concluding that a low to moderate level of environmental exposure to inorganic arsenic (0.02-0.05 mg/l) from drinking water does not have any dose-response relationship for arsenic and cancer.

From a study of Chilean cities, a description has been given of the causal role of arsenic exposure in developing lung and bladder cancers (Ferreccio *et al*, 1998) as well as the risk of kidney cancers (Hopenhayn-Rich *et al*, 1998). Smith *et al* (1998) reported from the study in Chile that ingestion of inorganic arsenic in drinking water is a cause of bladder and lung cancer rather than skin and kidney cancers. Deaths from cancer occurring between 1986-1993 in a study population of 263 blackfoot disease patients and 2,293 healthy subjects in Taiwan, were analysed as part of a cohort study by Chiou *et al* (1995) and a statistically significant positive association was found between ingested inorganic arsenic in drinking water (0–1.14 mg/l) and cancer of the lung and bladder.

Smith *et al* (1992) used the large Taiwan population and high arsenic levels in well-water (0.17-0.80 mg/l) to establish dose-response relationships between cancer risks and the concentrations of inorganic arsenic present in water supplies. They observed that arsenic is the cause of liver, lung, kidney, and bladder cancer and that the population risks cancer due to inorganic arsenic (Smith *et al*, 1992). A dose-response relationship was also observed between long-term arsenic exposure from drinking artesian well-water and the incidence of lung and bladder cancers (ATSDR, 2000).

In a cross-sectional biomarker study in a Chilean male population chronically exposed to high and low arsenic levels in drinking water. Moore *et al* (1997b) showed an association between inorganic arsenic and the lung and skin cancer. These results add additional weight to the hypothesis that ingesting arsenic-contaminated water enhances bladder cancer risk and suggest that arsenic induces genetic damage to bladder cells at drinking water levels close to MCL of 0.05 mg/l for arsenic (Moore *et al*, 1997a).

Chen *et al* (1985) investigated cancer mortalities in 84 communities in blackfoot disease endemic areas in Taiwan and found a statistically significant excess of bladder, kidney, skin, lung and liver cancer deaths for both males and females, compared to the Taiwanese population as a whole. Chen *et al* (1986) performed a case-reference study on malignant neoplasms in the same population and the results demonstrated an increasing risk of cancers of the lung, bladder and liver with increasing duration of arsenic exposure. Based on a total of 898,806 person-years, Chen *et al* (1992) observed a significant dose-response relationship between arsenic level in drinking water and cancer mortality. Mortality rates were associated with a variety of cancers including 64 for kidney cancers, 202 for liver cancers, 202 for bladder cancers, and 304 for lung cancers (Chen *et al*, 1992).

Wu *et al* (1989) analysed cancer mortality statistics for 42 villages in the blackfoot disease endemic area of Taiwan. The mortality data between 1973 and 1986 and the well-water arsenic concentrations had been monitored in the early 1960s and the age-adjusted mortality rates for lung, liver, kidney, bladder, and skin cancer showed a significant dose-response increase in relation to drinking water arsenic concentration in both men and women (Wu *et al*, 1989). In addition, Chen and Wang (1990) analysed the relationship between arsenic exposure and mortality from cancer at 21 different sites by multiple linear regression, indicating that the magnitude of the increase in risk associated with arsenic concentration in well-water was similar for both males and females for nasal cavity, lung, skin, bladder, and kidney cancers. Mortality from liver cancer was three times higher for men than for women. In addition, a positive association between well-water arsenic and mortality from prostate cancer was observed (Chen *et al*, 1992).

Chiang *et al* (1993) found a higher annual incidence of bladder cancer (23.53 per 100,000 persons) in the blackfoot disease endemic area; while Guo *et al* (1997) found increased incidence rates for bladder cancers and transitional kidney cell cancers due to increased exposures to arsenic. Tsai *et al* (1998) indicate that reductions in drinking water arsenic concentrations may have contributed to a decrease in the incidence rates of various cancers. Analysis of age-adjusted mortality rates for cancers of the lung, liver, bladder and skin combined in Taiwan, where there had been a fall in arsenic concentrations in drinking water since the 1970s, showed a gradual decrease in the risk of cancer in males aged over 40 years (Tsai *et al*, 1998). Smith *et al* (1998) carried out a similar study in Northern Chile.

In a further Chilean study, based on a set of 151 lung cancer patients, lung cancer risk was found to increase in a dose-response relationship (Ferreccio *et al*, 1998). The increased risk was statistically significant at concentrations of 0.03-0.05 mg/l and above (Ferreccio *et al*, 1998). In contrast, a recent analysis by Lewis *et al* (1999) indicated a slightly elevated, but not statistically significant mortality from kidney cancer in both males and females (SMR=1.75 and 1.60, respectively). Arsenic is also known as a clastogenic/aneugenic carcinogen and chronic exposure to arsenic causes cytogenic damage to humans (Gonsebatt *et al*, 1997). Besides, polyneuropathy (a peripheral neurological disturbance) also appeared in a study of Saha *et al* (1999).

2.3 ARSENIC DOSE AND RISK RESPONSE

Dose-response relationships between arsenic concentrations in drinking water and the dermatological manifestations in exposed populations are important issues in arsenic research. By dose-response relationship, we mean that, as the arsenic intake increases, both the frequency and the severity of toxic effects increase in the exposed population. The value of LOAEL (lowest observable adverse effect level) in this aspect is the key determinant for the dose-response relationship. LOAEL values of between 10 µg/kg/day and 18 µg/kg/day can lead to dermatological manifestations (Chakraborty and Saha, 1987; Hindmarsh *et al*, 1977; and Abernathy *et al*, 1999). The levels of arsenic that most people ingest in food and water (around 0.05 mg/day) are not usually considered to be of health concern (ATSDR, 1990). This opinion seems to be contradicted elsewhere. It is reported from various published materials that chronic exposure to inorganic arsenic in drinking water can be the cause of cancer and can increase risk even at very low exposures (WHO, 2001).

Brown *et al* (1989) calculated the lifetime risk of skin cancer to be 1.3/1000 for males and 0.6/1000 for females per microgram of arsenic per day (µg/kg/day); while the lifetime risk of dying from cancer of the liver, lung, kidney, or bladder from drinking 1.0 litre/day can be as high as 13 (Smith *et al*, 1992) or 100 (Smith *et al*, 2000a) per 1000 persons at the standard of 0.05 mg/l and 0.5 mg/l of arsenic respectively. The NAS (1999) reported that males who daily consume water containing 0.05 mg/l of arsenic have about a 1 in 1000 risk of developing bladder cancer. According to these studies, the people of Bangladesh and West

Bengal, India who are drinking water containing 0.05 to >1.0 mg/l of arsenic, are potentially exposed to high risk of internal cancers in the long term (Anawar *et al*, 2002).

The EPA (2000a) has calculated that lifelong ingestion of 0.001 mg/kg/day (around 0.05 to 0.1 mg/day in an adult) is associated with a risk of skin cancer of about 0.1% (1/1000). This dose level is comparable to drinking water containing 0.025 to 0.05 mg/l for a lifetime. Thomas *et al* (2001) pointed out the dose-response relationships for chronic exposure to arsenic as a toxin and a carcinogen; while Englyst *et al* (2001) found a correlation between lung cancer risk and exposure to inorganic arsenic. Charlet *et al* (2001) and Calderon (2000) also identified a potential health risk of chronic exposure to drinking well-water arsenic. Buchet and Lison (2000) focused on the evidence and uncertainties in reducing the risk from arsenic in drinking water. Hering (1996) described the procedures of assessing arsenic risk in drinking water with many limitations of achievable risk.

Gebel (2000) conducted a toxicological risk assessment for low-dose and long-term exposures to arsenic with experimental and epidemiological studies. Anawar *et al* (2002) pointed out the pattern of health risk due to exposure to arsenic. They suggested that about 20% of the total population who are drinking arsenic-contaminated water above 0.2 mg/l of arsenic are potentially exposed to a health hazard. These results are comparable with the calculated highly arsenic-affected population of about 18% (Chakraborty and Saha, 1987) and about 20% (Mandal *et al*, 1996) in West Bengal, India.

Data from the Taiwanese studies and from studies of other populations reveal that there is a dose-response relationship for ingested water arsenic and several non-cancer toxic effects (EPA, 1996b and NAS, 1999). The characteristic arsenical skin lesions may involve a latency period (the time from first exposure to manifestation of disease) of about 8 years (Brown *et al*, 1989), 10 years (Smith *et al*, 1992 and Guha Mazumder *et al*, 1998a), or 5-10 years (Milton and Rahman, 1999 and Tondel *et al*, 1999) depending arsenic dose content and immunity level (Smith *et al*, 1992 and Guha Mazumder *et al*, 1998a). There are some instances of patients with skin lesions in West Bengal (India), Taiwan and Chile who were drinking water containing very low concentrations of arsenic (Chakraborty and Saha, 1987; Lu, 1990; Guha Mazumder *et al*, 1998b; and Smith *et al*, 1992).

Morales *et al* (2000) reanalysed data from a study in an arseniasis-endemic area of Taiwan (Chen *et al*, 1992 and We *et al*, 1989) and estimated cancer risks for low-level waterborne arsenic exposures using a variety of statistical models with and without a comparison population. Morales *et al* (2000) concluded that, although the shape of the exposure-response curve is uncertain at low levels of arsenic exposure over a lifetime, one out of every 100-300 people who consume drinking water containing 0.05 mg/l of arsenic may suffer an arsenic-related cancer (lung, bladder or liver cancer) death. Smith *et al* (1992) predicted similar levels of arsenic risk; while Foster (2002) pointed out that the lifetime risk of death is 1 in 100 from consuming 0.05 mg/l and 1 in 50 from consuming 0.1 mg/l arsenic in drinking water. In a study from Ankara and Istanbul in Turkey, Karaer (1996) investigated the impact of high doses of arsenic on carcinogenic risk. In a study of the risk of bladder and kidney cancer in Finland in a cohort of people who had been using arsenic-contaminated drinking water over a period of 13 years (1967-1980), Kurttio *et al* (1999) found an increased risk of bladder cancer with increased arsenic intake during the third to ninth year prior to the cancer diagnosis, which reached statistical significance in the high-dose group.

2.4 SOCIAL STUDIES

Apart from health problems, arsenic toxicity creates widespread social problems for the victims as well as their family. The rural people of Bangladesh, due to their lack of knowledge consider arsenicosis to be a 'curse of nature' (Hassan, 2000). There is a tendency for unaffected people to maintain a safe distance from arsenic-affected people because they think that arsenicosis is like leprosy or some other contagious disease. In rural Bangladesh, communities affected by arsenicosis become almost completely isolated from others (Zaman and Rahman, 1998).

Some arsenicosis patients are facing serious social problems. Chowdhury (1997) in his popular article pointed out some social problems developed by chronic arsenic poisoning. They are isolated and people avoid them and they don't even go to the tea-stall. Zaman (2001) in her "Poison in the well" also discussed social problems of arsenic-affected patients. She observed a woman patient named Fatima being isolated from her family since there was a little chance of her getting married. Milton *et al* (1998) also observed difficulties in arranging marriage for young girls affected by arsenicosis. Also in a report by the WHO (1996), it was observed that arsenic problems in society become a headache for parents in getting their arsenic-affected daughters married. Chowdhury (2001) pointed out the same problem. Chowdhury (1997) also observed that some arsenic-affected housewives are divorced by their husbands, and some authors have found some arsenic-affected patients socially ostracised (Chowdhury, 1997; Chowdhury, 2001; and Milton *et al*, 1998).

In addition, arsenic problems have spread into the job market and qualified candidates called for interview may not be offered a job. These findings highlight the point that arsenic-affected people are becoming detached from social activities (Chowdhury, 1997). Roy (1998) pointed out that the social problems have gender aspects. He showed that arsenic-affected male patients are more common than female patients, but socially women are more prone to use the same source of water continuously than are men (Roy, 1998).

Haq (1997) and Schmetzer (1999) also described social problems related to chronic arsenicism. Haq (1997) pointed out the problems of school-going children, especially girls who go to school covering themselves and they are virtually isolated in society. The young women victims themselves and their parents are more aware of the social problems than they are of the arsenicosis disease. Bearak (1998) also describe the devastating social fallout caused by arsenic poisoning, especially divorce and the difficulty of getting married for arsenic-affected patients.

2.5 RESEARCH GAPS and TARGET AREAS

This chapter has attempted to identify the research gaps by exploring and reviewing the relevant literature on arsenic related issues concerning toxicity, existing health and social conditions of the affected people, arsenic and geology, arsenic and geochemistry, and arsenic and risk management (Figure 2.1).

From the above review and discussion of arsenic-related literature, I have seen that the chronic arsenic toxicity occurs by the consumption of contaminated drinking water much more than that of contaminated food. People drinking arsenic contaminated water develop various pathological manifestations in their bodies. The high general toxicity of arsenic has been known for centuries, and research during recent years has shown that arsenic is a potent human carcinogen.

Various reports indicate that tubewell water in most districts in Bangladesh is unsafe for drinking. Arsenic concentrations in most tubewells are found to be above 0.05 mg/l and presently millions of people are therefore at risk of arsenic poisoning. It is difficult to identify the level of actual intake of arsenic and how long people have been exposed to arsenic, so further health effects cannot be predicted. The recent detection of high arsenic concentration in numerous shallow (oxic) tubewells has caused serious public health concerns and these have become a great issue for Bangladesh. The people of Bangladesh are being continuously exposed to arsenic toxicity causing serious health hazards and alarm throughout the country.

Numerous epidemiological and ecological studies have shown that inorganic arsenic causes non-carcinogenic effects (Chen *et al*, 1988b; Col *et al*, 1999; Cebrian *et al*, 1983; Hernandez-Zavala *et al*, 1998; Santra *et al*, 1999; and

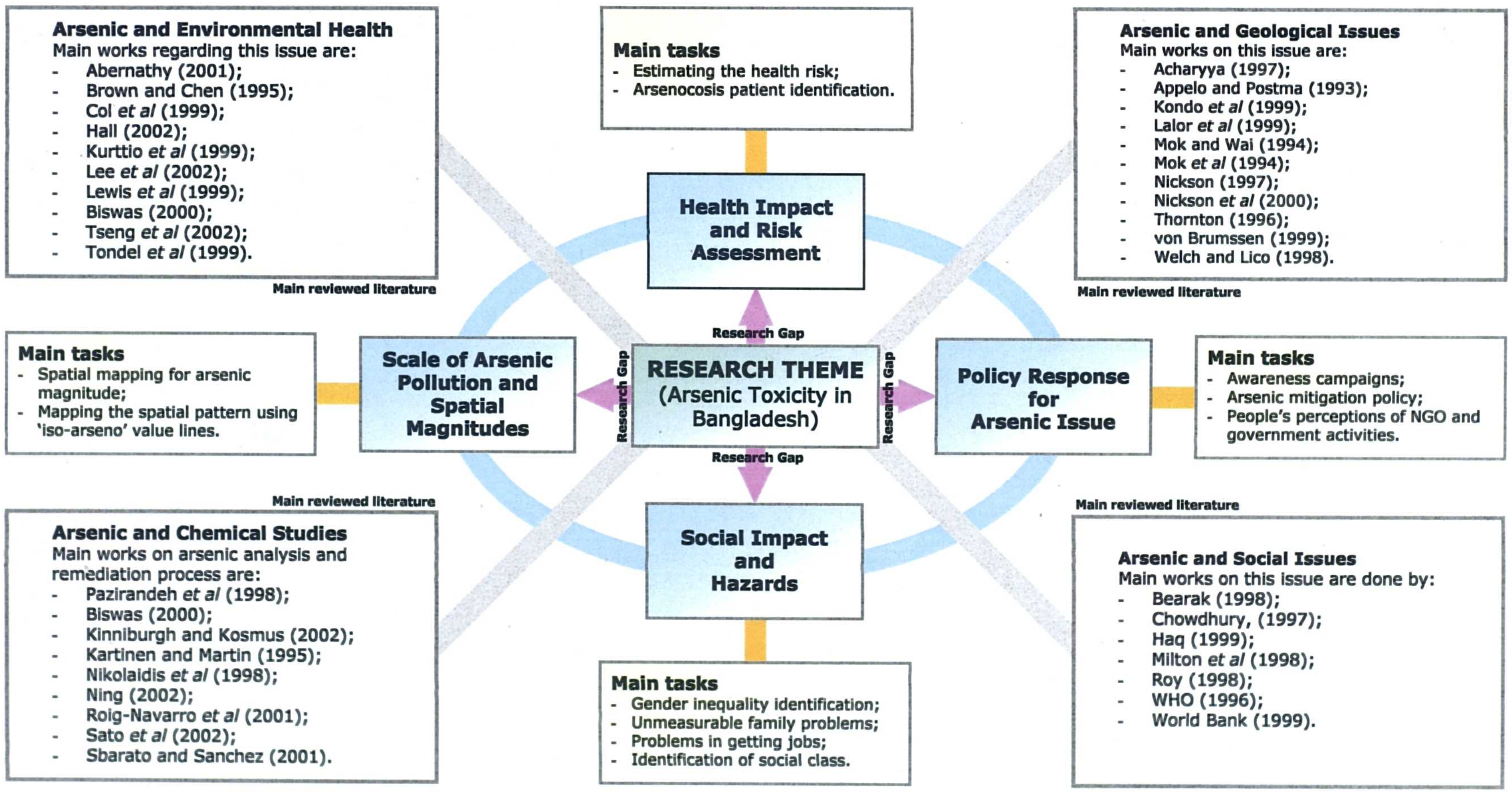

Figure 2.1 Reviewed literature on arsenic and identification of research gaps with aims to be analysed.

Tondel *et al*, 1999) as well as carcinogenic effects (Bates *et al*, 1992; Cuzick *et al*, 1992; Chiou *et al*, 1995; and Tseng *et al*, 1995) on the human body. But, there are a few research works on arsenic related risk assessment for Taiwan and Chile (Brown *et al*, 1989; Chen *et al*, 1992; Gebel, 2000; and We *et al*, 1989), and no established research works on risk assessment and risk management on arsenic poisoning in Bangladesh.

It is found from the review that there has not yet been any in-depth research concerning the social impacts of arsenic poisoning. Almost all of the literature shows some social problems in the forms of immeasurable family problems (problems in conjugal life, divorce, separation, problems in getting married for young unmarried women etc); problems in getting jobs; and overall social hazards due to arsenic poisoning. This research will find the social problems caused by arsenicosis and will also investigate how do the arsenic-affected people live with social hazards. Moreover, the development of participatory GIS operational structure for analysing arsenic poisoning in both health and social issues is also a central theme of this thesis. The followings are the research gaps identified from reviewed literature.

(a) **Geographical distribution:** Methodological limitations have been found in identifying spatial patterns of arsenic magnitudes. The highest arsenic concentration in each administrative unit of the same level has been considered to prepare choropleth maps (BGS, 1999; and Smedley and Kinniburg, 2002). This method does not show the true picture of the spatial distribution pattern of arsenic, but it does show the low to severe arsenic contaminated zones following the demarcating areas. In analysing the spatial pattern of arsenic magnitudes, spatial interpolation methods are helpful. The predicted "iso-arseno" value lines are important in identifying 'safe zones' and 'contamination zones'.

(b) **Environmental health risk:** In view of the above literature, it can be seen that there are rich research descriptions of arsenic-induced environmental ill-health, but there is a serious lack of epidemiological information on arsenic-induced environmental health risk in Bangladesh. Laboratory oriented in vivo results on rats and mice have been used to predict the impact on humans. Moreover, there has been no follow-up study on arsenic poisoning in Bangladesh concerning risk issues. The investigation of health impacts on humans could be advantageous in measuring chronic arsenic poisoning. It should also be noted that no literature has been found on the spatial risk pattern of arsenic. Thus, the mapping of 'spatial risk-pattern' is an important issue for this research.

(c) **Health problems:** A plethora of research work on the impact of arsenic poisoning on human health shows arsenic toxicity in the form of the symptoms of arsenicosis at different levels, rather than on the pain that arsenicosis patients suffer. Most of the literature shows "what kinds of diseases are caused by what amount of arsenic ingestion." There is a lack of information about the pain of arsenic-affected people concerning their health situation. There is even no literature about the survival strategies of arsenic-affected people, i.e. how they manage their health situation once challenged by arsenic poisoning.

(d) **Social problems:** In reviewing the existing literature, it can be seen that there is a lack of information on social issues of the arsenic-affected people. A small number of popular articles point out some social problems, but there is no proof whether these social problems are due to their economic disadvantages or due to arsenic poisoning. Apart from this, there is no information on how the arsenic-affected people live with social hazards.

(e) **Arsenic mitigation and policy response:** A number of publications discuss different remediation procedures: (a) removal of arsenic through the use of chemicals in treatment plants; and (b) low-cost household remediation processes. There is no information, however, on awareness campaigns, which is an important aspect in preventing arsenic poisoning. In the Bangladesh context, it can be seen that many NGOs, organisations and professional bodies are working for the removal of arsenic from groundwater, but it is not noted whether these technologies are viable given the current socio-economic conditions of the poor arsenic-affected people. The policy response by the government and NGOs on arsenic mitigation is important, but their policies need to be viewed in the light of the people's own opinions about what is feasible for both short-term and long-term mitigation.

2.6 CONCLUDING REMARKS

This thesis is inspired by the current scientific interest in arsenic poisoning on environmental risk, adverse health and social effects as well as public policy in Bangladesh. This chapter has explored the literature on groundwater arsenic issues in different aspects, which have provided insights into the nature of the existing pattern of arsenic research. In reviewing the literature, I have found a research-focus on arsenic toxicity in the form of health problems at different levels of arsenicosis, but little qualitative research on the inherent problems that arsenicosis patients themselves identify.

There has been an increasing interest in arsenic research over the last several years. Many empirical studies have been undertaken to explore the hydrological, geological, geochemical and medical studies and these provide a framework for discussing concentrations of arsenic, source of arsenic, its toxic nature, and its impact on human health.

From the many hydrological, geological and geochemical studies, it can be seen that arsenic concentration is especially high in groundwater from pyrite-rich sedimentary aquifers. The aerobic hypothesis (Acharyya *et al*, 1999; Appelo and Postma, 1996; and Das *et al*, 1995) and the anaerobic hypothesis (Lalor *et al*, 1999; Mok and Wai, 1994; and Nickson *et al*, 2000) are the two established theories to explain the release of arsenic in groundwater. This chapter has also privileged the literature on different analysis methods of measuring arsenic concentrations in groundwater. The AAS, GF-AAS, ICP-AES, ICP-MS, FI-HG-AAS, and XRF are widely used in analysing arsenic concentrations. In addition, I focussed on the remediation issues of arsenic from groundwater and discussed the merits and demerits of different removal techniques of arsenic from groundwater.

The ingestion of inorganic arsenic has long been associated with marked toxic effects on human health. There is a lot of literature on arsenic-induced environmental health effects. The case-control studies from Taiwan, Chile, Mexico, Argentina, West Bengal and Bangladesh show the pattern of health problems caused by chronic arsenic ingestion. The chronic ingestion of inorganic arsenic causes diseases from melanosis to cancer in terms of tracheal and bronchogenic carcinomas, hepatic angiosarcomas (Bates *et al*, 1992), and various skin cancers (ATSDR, 2000).

This chapter also focussed on the literature on arsenic-dose patterns and risk response. The LOAEL and NOAEL (no observable adverse effect level) factors have been used in much research to measure the risk pattern. The 'risk-factor' is also an important parameter and it can be used to fill a gap in arsenic-induced health risk assessment. It has been found from some popular published sources that different social problems are caused by chronic arsenic ingestion. I noted that there is no core research on these social problems in Bangladesh.

The chapter has addressed and explored selected research output on arsenic issues from several literatures. The next chapter (Chapter III) will mainly focus on the data collection procedures and the data analytical procedures used to fulfil the research objectives. Spatial, statistical and qualitative research methods will be employed to reach the research targets described in the previous chapter (Section 1.8). In addition, I will return to the issue of the laboratory analysis of arsenic in water samples for accurate and efficient data.

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CHAPTER III

DATA and METHODOLOGY

CHAPTER – III

DATA and METHODOLOGY

In Bangladesh, drinking water is the major source of arsenic poisoning in humans. The recent detection of high arsenic concentrations in tubewells has caused serious public health problems and social concerns have become a great issue. The study attempts to explore the impact of arsenic on health and social issues in the study area. This research also focuses on the geographical pattern of arsenic concentrations and analyses 'spatial risk zones' for composite arsenic hazard information. Participatory techniques and different qualitative methods were adopted in order to represent local people's perceptions about environmental health risk and societal problems which have arisen from the impact of arsenic poisoning.

The materials presented in this chapter are aimed at providing the sources of data and the methods for relevant data analysis. This chapter is divided into eight sections. The following section deals with the preparation of a base map for the study area. Section 3.2 presents the field survey planning and research design. Section 3.3 describes the sampling procedures for both the quantitative and qualitative researches. Section 3.4 shows the details of quantitative data collection procedures for groundwater arsenic concentrations and health issues. Section 3.5 deals with the qualitative data collection techniques regarding health and social aspects of arsenic impact. Section 3.6 describes the methods for analysing both the quantitative, spatial and qualitative data. Section 3.7 explores the limitations of data and methodologies, and the last section makes some concluding remarks.

3.1. BASE MAP PREPARATION

In order to facilitate the use of spatial information in a GIS, various geographically referenced maps were used. Besides plotting tubewell locations, mapping the surface water sources and visualising different map features, a base map with detailed information was essential. The base map was mainly collected from the Department of Land Records and Survey (DLRS) of Bangladesh (Table 3.1). The DLRS is the only government organisation having the authorisation to prepare and sell *mauza* maps. Since the study covers a whole *union*, we needed to collect the *mauza* maps. Joining the *mauzas* together, a complete *union* map with boundary information was prepared. This boundary information from the DLRS was converted and recorded in a GIS digital format.

Table 3.1
Sources of map data for base map preparation.

Sources	Map title	Scale	Basic features	Purpose for this study
DLRS	*Mauza* maps (RS maps)	1:3960	Plot boundary, rivers, canals, small roads and some buildings	Locating and plotting tubewells
LGED	*Upazila* maps	1:50000	Boundary information from *mauza* to *upazila* levels and physical features	Point, line and polygon features identification
BBS	Small area atlas	1:100000	Boundary information for *mauza* and demographic features	Settlement area identification and population distribution
SRDI	*Upazila* soil maps	1:50000	Boundary information for *upazila* level and soil associations	Geological features and landforms identification
SoB	Topo maps	1:50000	Topographic information and different map features	Surface water sources, roads and other physical features

* **DLRS:** Department of Land Records and Surveys; **LGED:** Local Government Engineering Department; **BBS:** Bangladesh Bureau of Statistics; **SRDI:** Soil Resources Development Institute; and **SoB:** Survey of Bangladesh.
Sources: DLRS, 1982; LGED, 1994; BBS, 1993; SoB, 1998 (Topo map); and SRDI, 1992.

The physical features of the study area were also collected from secondary sources (Table 3.1). The Local Government Engineering Department (LGED) has produced the *Sadar Upazila* map of Satkhira. This map covers the boundary information of *mauza*, *union* and *upazila*; some physical features in terms of roads, rivers, canals, settlement areas, infrastructures and so on; and some socio-economic characteristics. Other useful maps include one produced by the

Bangladesh Bureau of Statistics (BBS) which has boundary information and the distribution of some demographic parameters, and another by the Soil Resources Development Institute (SRDI) has geological features and soil associations. In addition, there are maps produced by the Survey of Bangladesh (SoB) with topographical and physical features.

Apart from the *mauza*, *union* and *upazila* boundary information, there are various map features in terms of rivers, canals, waterbodies, roads, settlement areas, agricultural lands, commercial areas, as well as geological features and soil associations, which were extracted from different map sources (Table 3.1). This map information was categorised into different point, line and polygon layers and finally appended on to the main coverage of the *mauza* and *union* boundaries in developing a complete 'base map' for this study.

3.2. FIELD SURVEY and RESEARCH DESIGN

The field survey and research design for this thesis was based on the aims and objectives in relation to the research questions. The investigation of arsenic toxicity on health and social issues employed multiple methods (Table 3.2). This strategy provided a mix of both quantitative and qualitative data, with the extensive questionnaire survey providing breadth of coverage, while the interviews with tubewell holders, in-depth interviews with different respondents, and focus-group discussions allow a greater depth of understanding of the health and social hazards and human responses to it. The design was composed mainly of problem formulation, qualitative and quantitative data collection procedures and manipulation, data analysis and interpretation, and performing geographical and participatory analyses with a GIS output (Figure 3.1).

3.2.1 Field survey planning

The survey design was organised as a data collection procedure to address the impact of arsenic exposure. The data were collected from both the primary and

Table 3.2
Methodological approaches adopted for this research.

Research approach (Type of Science)	Main methods (School of thought)	General description	Importance in arsenic research	Data collection procedures	Data analysis procedures	Target covered
Quantitative approach (Empirical-analytical)	Empiricism	In empiricism, facts are believed to speak for themselves and require little theoretical explanation (May, 1993). It can be used to explain the normative and metaphysical questions.	Facts about arsenic issues would be collected and presented for interpretation (i.e. health aspects, social hazards etc).	Presentation of experienced facts.	- PRA methods - Narrative approach	General arsenic poisoning.
	Positivism	It refers to the determination of laws to predict and explain questions in terms of cause and effect. It requires propositions to be verified (logical positivism) or hypotheses falsified (critical rationalism) rather than just simply presenting findings. It rejects normative and metaphysical questions that cannot be measured scientifically.	Arsenic concentrations can be explained through testing a hypothesis by collecting and scientifically testing data related to arsenic issues (e.g. statistically testing whether arsenic is a function of depth).	Water sample collection, laboratory analysis, spatial data collection and questionnaire survey.	- Statistical analysis - Spatial/GIS analysis	Scale of arsenic concentrations, arsenic and depth relationship.
Qualitative approach (Historical-hermeneutic)	Phenomenology	It refers to the 'people-centred' form of knowledge of an object based in human awareness, experience and understanding. It reconstructs the meaning of phenomena and objectives in the worlds of individuals to understand the individual behaviour without drawing upon supposed theories (Kitchin and Tate, 2000). It rejects the scientific and quantitative approaches of positivism. It seeks to disclose the original way of being prior to its objectification by the empirical sciences (Pickles, 1985).	To understand the arsenic poisoning, it needs to reconstruct the world of arsenic affected people (i.e. it is essential to observe the arsenic poisoning through the eyes of affected people).	Participant observation, in-depth interviews, focus-group discussions and ethnography.	- Discourse analysis - Heuristic approach - Grounded theory	Impact of arsenic.
	Existentialism	It is based on the notion that reality is created by the free acts of human agents, for and by themselves (Johnston, 1986). It focuses upon how individuals come to create and place meaning to their world and how they subscribe values to objects and to others.	How arsenic-affected people come to know the meaning of arsenic poisoning and how they think that they are socially affected due to arsenic poisoning)	In-depth interviews, ethnography, Focus-group discussion, and participant observation	- Ethnographic approach - Hermeneutical analysis	Social hazards.
	Pragmatism	It suggests that rather than focussing on individuals, attention should be paid to society and the interaction of individuals within society. By exploring the lives of people within a community, it is hoped that the nature of the beliefs and attitudes, which shape society, will be uncovered (Kitchin and Tate, 2000).	Arsenic poisoning is understood by observing how individuals in a society interact to social myth (e.g. examining whether affected people recovering their problems or suffering more).	Ethnography and participant observation.	- Narrative analysis	People's perceptions *about arsenic* poisoning.
Critical research	Realism	It refers to the investigation of underlying mechanisms and structures of social relations, i.e. identifying the 'building blocks' of reality. It concerns the identification of how something happens (causal mechanism) and how extensive a phenomenon (empirical regularity) is (Unwin, 1992).	Arsenic hazard is understood by determining the mechanism underlying how society operates (e.g. examining whether arsenic hazard exists because of the uneven social attitudes).	Mixed qualitative and quantitative.	- Statistical analysis - Narrative analysis	Role of society in arsenic mitigation.

Note: The methodology of this research is combined with these approaches in covering the both quantitative and qualitative objectives.

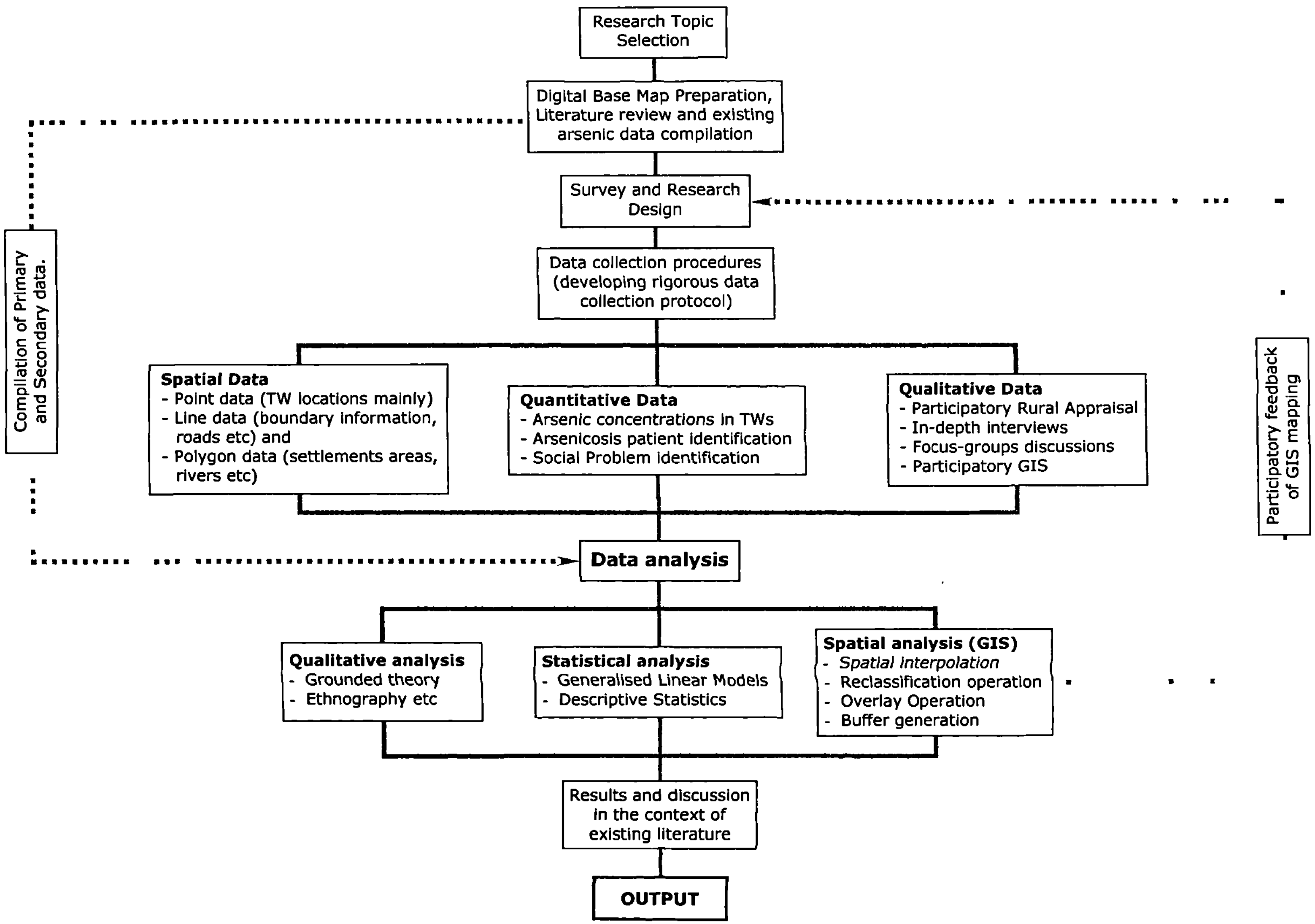

Figure 3.1: Flow chart of survey and research design.

secondary sources. The primary information for this study included empirical field observations and field level data collection through inventory, questionnaire survey and interviews with different participatory techniques. The secondary information was collected through a literature survey on the study of Bangladesh arsenic issues and also through surveying relevant published and unpublished materials.

Getting in: Before starting my field survey in the study area for collecting the relevant arsenic data, I introduced myself to the local leaders and I told them about my activities and asked them for their cooperation. I made specific arrangements for several meetings with the local leaders and local elected administrative authorities (chairman and members) about my work schedule and how to develop ideas to mitigate arsenic toxicity.

After getting a positive sign from local leaders and local administrative authorities, I arranged a reconnaissance survey for getting primary ideas of the overall physical and social conditions of the study area. In addition, **p**articipatory **r**ural **a**ppraisal (PRA) surveys were conducted to gain a quick understanding about the "after-shock" of a flood event. The people of the study area had just experienced their first devastating flash-flood for half a century.

Getting along: After "getting in", I tried "fitting in" with the local people in the study area with some difficulty. When the flood-affected people saw strangers, they asked them for flood-aid. When people asked me for aid, I was unable to provide them with anything. On one occasion, a man told me angrily that, ". . . forget your arsenic, we have lost our property – the flood damaged everything, we need food, either give us food, or leave our village." When people were trying to normalise their lives just after such a devastating flood, it proved to be really difficult to conduct fieldwork on arsenic issues.

Although I faced many negative situations, I continued to meet people and told them about the poisonous nature of arsenic and also showed them some photographs of arsenic-affected patients. Then they understood and within a few weeks people were willing to cooperate in my activities. In addition, after analysing arsenic concentrations in groundwater, I went to every tubewell a second time to let people know about the arsenic concentrations in their tubewells. My experience on these second visits was totally different. People were happy to talk to me.

After "fitting in" properly in the study area, I adopted a number of different approaches, both formal and informal in order to gather data. For instance, each morning I would provide breakfast for a number of people in the village I was visiting. This broke the ice and conversation often turned to matters of relevance and importance for my research. In addition, I mixed socially with local leaders, for instance, in afternoon sessions, I used to play caram, a Bengali board game. Again I learned a lot from these encounters and found generally that I could understand much of the background context of a locality by sharing the lives of local people.

In the data collection, in-depth interviews and focus-group discussions were adopted. Apart from this, the dialectic approach was used to confirm the credibility of stories and examine the 'cross-case themes' (Brown and Gilligan, 1992) that I gathered from in-depth interviews and focus-group discussions.

3.2.2 Research design

In the research design, the quantitative data for the arsenic concentrations in the study area comprised a combination of spatial and attribute information. The spatial data in terms of point (X and Y coordinate values for a TW), line (string of X and Y coordinate values for a road) and polygon (identical X and Y coordinate values for the beginning and ending points of planimetric information were administered into a GIS framework (Appendix-A). The attribute data of map features (i.e. tubewell identification number, tubewell depth, arsenic concentrations, etc) were collected from primary sources. In addition, different quantitative information in terms of users of each tubewell during the winter and the summer seasons, the pattern of water availability in each tubewell, and the installation year etc were imported into the GIS environment. The tubewell holders (375 tubewells) were asked for information about the attributes of their tubewells, their demographic characteristics and their opinions on many issues of arsenic poisoning through a questionnaire survey (Appendix-B).

The PRA and the Participatory GIS (PGIS) techniques were incorporated in collecting the qualitative data. The PRA techniques were adopted prior to and during the formal data collection procedures; while the PGIS techniques were used during the in-depth interviews and focus-group discussions. Communities are not homogeneous in their characteristics. The in-depth interviews were arranged to get a greater depth of understanding of the suffering of the arsenic affected-people and their responses to it. The focus-group discussions were also arranged to gain a better community-based understanding of arsenic poisoning and social issues, and the mitigation options.

In order to fulfil the aims and objectives, the research tasks were structured as follows:

(a) Collection of secondary data. Very little information regarding arsenic issues exists in Bangladesh and certainly not enough for this thesis. I therefore collected my own primary data from my study area.

(b) PRA techniques were used in five *mauzas* in order to gain a general and quick understanding of the scale of the problem.

(c) All of the tubewells were screened in order to allow the compilation of a GIS for the pattern of arsenic magnitudes in the study area. There were issues about the number of tubewells that were tested, and also about access to a laboratory method.

(d) From arsenic data, I selected patients and water consumers exposed to different levels of arsenic concentrations in order to understand their perceptions of risk and the social implications of arsenic poisoning. Some 23 in-depth interviews were conducted.

(e) In each village or ward under scrutiny, general background data were collected by PRA techniques. PGIS techniques were also used in the formulation of "spatial participatory opinions" for the mitigation of arsenic problems.

(f) Focus-groups provided some community-specific information, but they also yielded data relevant to particular stakeholders such as teachers, farmers, health workers and government employees and so on. In addition, discussions with government officials and NGOs yielded important insights into policy towards the mitigation of the arsenic hazard. Some five focus-groups, each with 6-10 members, were selected for this research.

3.2.3 Problems faced during fieldwork

From the very beginning of my fieldwork, I faced the following difficulties in collecting relevant data:

(a) I was continuously facing problems from some people who had lost their property in the recent flood. They asked me for aid, and when I was unable to provide them any, they tried to hamper my activities. In conducting my field survey, I employed three local people to assist me. One was a non-literate daily labour worker. He knew the exact location of almost all tubewells and also knew the local environment in terms of roads, settlement areas, schools and *madrasas*. The second assistant was a political figure in the study area. When I was facing continual problems in collecting water samples following the devastating flood, in some cases, he played a key role in resolving these problems. The third assistant was a van driver (in rural Bangladesh, a van is a pedal controlled three-wheeler). His van was hired as a means of transport around the study area to carry water containers, ice boxes, chemicals and painting materials. In addition, my younger brother (a Lecturer in Geography) also provided general field assistance.

(b) A total of five female respondents, of which four were arsenicosis patients were selected for my in-depth interviews. It is noted here that, as a male researcher, I did not face any specific problems in conducting these interviews. A number of female participants were invited to participate focus-group discussions, but only two were willing to share their opinions and feedback regarding arsenic-related issues. When I raised this issue in the group discussions, most participants alluded to the conservative nature of Muslim societies and I felt that it would be easier for a female researcher to collect relevant primary data from female participants on another project. Similarly, it was not possible to have a focus-group representing the occupation of "housewives".

(c) Some people were angry with us when they saw us collecting water from their tubewells. They thought that we were from the Department of Public Health engineering (DPHE) and that we were going to pull out all of the tubewells in the study area. Just after the recent flood some DPHE men had visited the area and pulled out a few government tubewells.

(d) Some people thought that we were from the NGOs and that we were there to purify the water by putting bleaching powder into their tubewells. They were not satisfied with this treatment process because of the chlorine smells and they felt unable to use that water. Again, just after the flood, some NGOs and other organisations had indeed put bleaching powder into tubewells to purify the water.

(e) Some people asked me about the benefit to them of my collecting water samples from their tubewells. They also asked me whether we would provide them with arsenic-free water. In some occasions, I faced anger. One man told me that, ". . . if you do not provide a deep tubewell, you must not work in this village. Many NGOs did the same work, they promised people deep tubewells, but they did not deliver, and you will do the same."

(f) Some people asked me to check their tubewells first. When I told them about my systematic plan of work, they sometimes tried to create problems. A few people told me directly that they would not cooperate with me in getting water from their tubewells. On such occasions, I told them that, ". . . I will analyse your tubewell free of cost. If you do not agree with my approach you can always have your water checked in Satkhira but it will be expensive". When they understood that a free service was being provided, most people decided to cooperate.

(g) Before collecting the water samples, I arranged a meeting with local leaders and the local elected chairman and members to discuss how to collect information. They agreed that members of every ward would provide me some information about the tubewells located in their respective areas. I gave them a data proforma (Appendix - C) for recording elementary information about each tubewell. I gave three days to complete the sheets. After collecting the filled-in sheets, I started to gather water samples and I found that a remarkable number of tubewells were not listed. People told me that the elected members had listed only the tubewells owned by their political supporters. In addition, I found a lot of incorrect information about the location of tubewells (plot number), installation year, and depth of each tubewell. I checked the provided information during the collection of water samples and rechecked them during my second visit to each tubewell when I was providing feedback about the nature of the arsenic concentrations in their tubewells.

3.3. SAMPLING STRATEGY: PRINCIPLES and APPROACHES

In collecting both the quantitative and qualitative information, it was essential to have a sampling strategy and sample size for the tubewells as well as respondents for the in-depth interviews and the participants for focus-group discussions. The sampling method gave me a structure and strategy for collecting both quantitative and qualitative data in the field and forced me to keep in mind the problem of possible bias.

3.3.1 Probability sampling: tubewell screening

In most quantitative inquiry, the dominant sampling strategy is probability sampling. The purpose of probability sampling is the subsequent generalisation of the research findings to the whole population (Hoepfl, 1997). In the present research, a rather different sampling strategy was followed. Tubewell screening is the most important priority work for analysis the arsenic concentrations in tubewell water. Which tubewells would be screened and how many? This was an important and sensitive issue in the context of present arsenic situation in Bangladesh. My previous experience (June 1999) in this regard was taken into account. When I started to screen tubewells (Marua village in Jessore district), people asked me when their tubewells would be screened and I was faced with pressure from the villagers. On this occasion I tried to make it very clear from the moment of entering the study area that this research is academic and has no bearing upon the health circumstances of individuals or families. This was not an easy message to convey.

Evidence from several papers concerning the arsenic concentrations in Bangladesh (Acharyya *et al*, 1999; BGS, 1999; Bhattacharaya *et al*, 1998; and Nickson *et al*, 2000; and Saha *et al*, 1999), as well as my previous field experience (June 1999), indicated that arsenic distribution is highly uneven. For instance, in one arsenic contaminated area, 5% of tubewells were found to be safe from the same aquifer level that fed 95% of tubewells in the same village that were found to be contaminated. In an adjoining village, only 12% were contaminated.

To avoid the apparent chaos of observations in the study area and to determine the 'true picture' about the pattern of arsenic magnitudes in the study area, I decided to collect water samples from all of the tubewells that existed in the study area. Accordingly, a total of 375 tubewell water samples (some damaged tubewells were not considered) were gathered. This was helpful in identifying the geographical pattern of arsenic magnitudes and the different 'problem regions'.

3.3.2 Non-probability sampling: selection of respondents

In collecting the qualitative information, it is essential to select a sampling strategy for the in-depth interviews and the focus-group discussions. The qualitative research is not intended to be representative of the whole population. Thus, in this part of the inquiry, the dominant sampling strategy is non-probability sampling, in which the choice of units in the sample depends on the researcher and there is no way of estimating the probability of each unit being included in the sample. There is no 'strict criterion' (Patton, 1990) for sampling and sample size in qualitative research.

The particular sampling design of a qualitative study depends on the purpose of the inquiry, what information will be most useful and what information will have the most credibility (Hoepfl, 1997). The choices of respondents to this research were the product of what was being found, not what was in the initial theoretical plan. Once the general pattern of arsenic concentrations was known from tubewell screening and patients were identified, then I proceeded to select some users for in-depth interviews. The purpose here was to investigate the health situation of the arsenic-affected people, their perceptions about risk and the social impact of arsenic poisoning.

Purposive sampling is the dominant strategy in qualitative research (Patton, 1990) and the most useful strategy is maximum variation sampling (Lincoln and

Guba, 1985). Maximum variation sampling aims at capturing and describing the central themes of a problem (Hoepfl, 1997; Patton, 1990; and Ratcliff, 1999). Since long time-periods are required to ensure successful qualitative research, the sample size is, thus, usually small and the number of interviews is less important than the quality of data collected. The sampling aims at achieving as much information as possible about the issued studied (Bunne, 1999). The qualitative researchers often work with a small sample size, deriving detailed information on participants in their living context, gaining a "thick description" (Geertz, 1973) of specific situations, and seeking patterns in complexity rather than a simplifying consensus overview (Rich and Ginsburg, 1999).

In this kind of work, it may well be that twenty or thirty is the maximum number of interviews that can be accomplished. Since the arsenic issue is a very sensitive one in the region, the selection of specific interviewees had to be very carefully planned. Cluster sampling was used to select respondents and a random sample within each cluster was comprised of a large number of people who felt able to participate in the non-affected category. The sample size naturally depends on the study questions. Some 23 in-depth interviewees and 5 focus-group discussions were selected for the qualitative data collection procedures. In all 11 arsenicosis patients were selected for in-depth interviews.

3.4. QUANTITATIVE RESEARCH and DATA COLLECTION

The quantitative research based on logical positivism uses a process of testing hypothetical generalisations. It produces causal determinations, predictions, and findings by using quantitative measurements and by the application of statistical and mathematical analysis. Quantitative methods achieve rigour in part by fixing the hypothesis and the method for testing it at the outset of a study (Bunne, 1999; Ratcliff, 1999; and Rich and Ginsburg, 1999).

3.4.1 Arsenic data from groundwater

The water data that I collected from tubewells were used in spatial analysis, mapping the pattern of arsenic concentrations in space-time dimensions. In order to identify the present scale of arsenic concentrations in the study area, field data were collected. A minimum detection limit (MDL) was essential for establishing the spatial distribution of arsenic and one permissible limit is the 0.01 mg/l (WHO permissible limit) that is essential for arsenic safety, although, the DoE (1994) set a different maximum contamination limit (MCL) of 0.05 mg/l of arsenic for Bangladesh. The methods and analyses of arsenic in groundwater are well-known and described in the literature (Irgolic *et al*, 1987). The data mainly addressed the concentrations of inorganic arsenic available in the groundwater of the study area. The data were collected by testing 375 tubewells in the study area through the laboratory analysis.

Suitable arsenic analysis technique: A number of methods are available for groundwater arsenic analysis in Bangladesh, of which the Field Test Kit (FTK) methods in terms of E-Merck kit, ANN-NIPSOM modified kit, AQUA-Consortium kit etc, are important. The FTK methods are easy to conduct and are cost-effective, but are less reliable than the laboratory methods. Some FTKs provide semi-qualitative results, while some provide qualitative results i.e. only a 'yes/no' result. In the FTK methods, the lower arsenic concentrations are more difficult to detect. At the lower levels of concentrations, the reliability of the test is not good, but at the higher concentrations, the FTK provides nearly accurate results. All the FTKs are based on the Mercuric Bromide Stan Method (MBSM)[1] (BGS, 1999). The lower level of arsenic detection capabilities of each FTK is different.

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[1] It is not suitable for quantification of arsenic below 0.05 mg/l. The precision and accuracy of this method are not acceptable. At a concentration of more than 0.2 mg/l, the average results come out with a 21% error. This method can certainly not to be used to quantify arsenic concentrations below 0.1 mg/l.

The ANN-NIPSOM modified kits show positive test results for arsenic at 0.01mg/l sulphide level, even when there was no arsenic present in the sample. The minimum detection limit of ANN-NIPSOM modified kit is 0.02 mg/l and the value for the E-Merck kit is 0.1 mg/l; while the AQUA-Consortium kit can detect the presence of arsenic at more than 0.05 mg/l (Table 3.3). The AQUA Consortium kit is also known as a 'Yes/No' kit since there is no colour comparator. In the AQUA Consortium kit, colour develops on the mercuric bromide paper when the arsenic concentration is more than 0.05 mg/l. In addition, the Arsenator-510 has recently been introduced as a high quality testing kit for groundwater arsenic analysis. The minimum detection limit of this kit is 0.0005 mg/l and its precision ranges between 1-5% (Kosmos, 1998).

Arsenic measurement procedures and measurement scales are different in different FTKs. In the ANN-NIPSOM modified kit, the colour measurement scale varies from light-yellow to brown. I found variations of colour measurement scales in different kit boxes during the analysis of arsenic concentrations in 1999. Moreover, temperature and humidity variations can lead to variations of accuracy of the ANN-NIPSOM kit measurement scales.

Variations of the colour measurement scales are not as much in the E-Merck kit, but a problem with this kit is that the minimum detection limit of 0.10 mg/l is 10 times higher than the WHO (1994) guideline value for the permissible limit of arsenic in drinking water and twice as high as the DoE (1994) guideline value (0.05 mg/l) for Bangladesh. The alternative AQUA-Consortium kits are not suitable because they have no comparator for the measurement of arsenic concentrations. The best option, in this regard, is the Arsenator-510 which has an excellent detection limit range. The determination of low concentrations of arsenic is reliable. Although the use of this kit is very expensive, I originally decided to use this kit for my analysis, but at the last minute, when I came to know of its interruptible power supply, I changed my mind and decided to go instead for a suitable laboratory method.

Table 3.3

Comparative details of different field-test kits.

Parameter	ANN-NIPSOM	AQUA-Consortium	E-Merck	ARSENATOR-510	FI-HG-AAS
Dimension (in mm)	210x80x220	195x95x170	180x145x55	270x200x105	-
Weight	1.6 Kg	1.2 Kg	1.1 Kg	3.2 Kg	-
Power supply	-	-	-	9.6v NiCD Battery	Electrical
Power capacity	-	-	-	10 hours	-
Colour & Display	Yellow to brown	Orange	Orange to brown	LCD (4 rows)	-
Ambient temperature	-	-	-	10^0-45^0C	-
Chemicals	Yes	Yes	yes	Yes	Yes
Per analysis time	5 minutes	15 minutes	30 minutes	9 minutes	<1 minute
Detection limit (mg/l)	0.02 - 0.70	>0.05 ('yes/no' kit)	0.10 - 3.0	0.0005 - 2.50	<0.003
System costs*	1,000	2,000	3,000	200,000-00	15,000,000
Test per kit	100	100	100	Depends on chemicals	Depends on apertures
Consumable cost*	10	20	30	100	175
Country of origin	Japan-Bangladesh	India	Germany	Austria	-
Merits and demerits	Lower DL value is not accurate and problem in colour scale.	No lower value and no accuracy. Not suitable for arsenic research.	Lower DL value is high and maximum analysis time. Not suitable to detect the WHO, EPA & DOE permissible limit.	Excellent DL values. But, the main problem is in its power supply.	Excellent DL value. Can be analysed the arsenic in water with minimum error.
Overall comments	Moderate	Not suitable	Not suitable	Good	Excellent

* In Bangladesh Taka (BD Tk100 = £1.20 or $2.00).

Sources: BGS, 1999; Kosmos, 1998; WHO, 2001; and http://www.arsenator.com

In addition to these FTK methods, various laboratory techniques have been used in the determination of arsenic concentrations in groundwater. Several methods (GF-AAS, HG-AAS, ICP-AES, ICP-MS, XRF, etc) for the determination of arsenic has been discussed in the previous chapter (section 2.1.2). In the laboratory, accurate arsenic concentrations are easily detectable and the tests are reliable. They are advanced in technology but the costs of both the equipment and the consumables are very high. The FI-HG-AAS was selected for analysing groundwater arsenic concentrations in the study area (Figure 3.2).

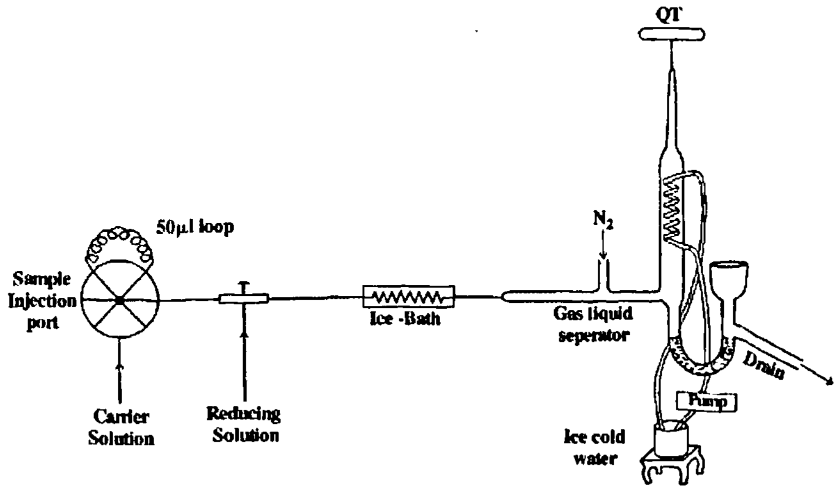

Figure 3.2: Schematic diagram of FI-HG-AAS system.
Sources: Biswas, 2000 and Samanta *et al*, 1999.

The HG-AAS method has been widely used for the determination of arsenic in biological and environmental samples (Arenas *et al*, 1998; de La Calle-GuntiÑas *et al*, 1992; Le *et al*, 1992; and Lopez *et al*, 1992). Since the method is time-consuming, scientists have developed the FI-HG-AAS technique for determination of arsenic. In FI-HG-AAS method, a flow injection system is coupled with HG-AAS and hence the FI-HG-AAS (Biswas, 2000). The method is characterised by high efficiency, low sample volume, reagent consumption, improved tolerance of interference, and rapid determination (Brindle *et al*, 1992; Le *et al*, 1992; and Samanta and Chakraborti, 1997). With a 95% confidence level, the minimum detection limit of the FI-HG-AAS method is 0.001 mg/l, and the quantification limit is 0.003 mg/l (Samanta *et al*, 1999), which is excellent for arsenic research.

Collection of water samples: An important consideration was how to collect water samples from tubewells and preserve them until analysed. An accurate and precise analytical technique is useless without good quality samples (Rasmussen and Andersen, 2001). For instance, I pumped each tubewell 25-30 times in order to produce non-stagnant samples. Stagnant samples are not representative and do not allow accurate detection since arsenic is a heavy metal.

Samples were collected in pre-cleaned plastic containers having a capacity of 15 ml. Glass containers are not recommended as some glass materials contain arsenic (Rasmussen and Andersen, 2001). Before sampling, all of the containers were cleaned up again by the water tapped from each respective tubewell in order to ensure that there is no significant contamination of the containers. Only 10 ml of tubewell water was collected for a sample.

In order to prevent adsorption losses, compromising the detection limit, accuracy and precision of the analyses, the collected samples were preserved by acidification. Acid digestion is the basic method and nitric acid is recommended for samples to undergo analysis by FI-HG-AAS prior to the preservation and measurement (Rasmussen and Andersen, 2001). Accordingly, a drop of concentrated nitric acid was added in each 10 ml of water sample as a preservative (Chatterjee *et al*, 1993). The samples were then kept in an ice-box and placed in a refrigerator at a temperature below 4^0 C until the data were analysed in FI-HG-AAS at the School of Environmental Studies, Jadavpur University, Kolkata, India, about 85 kms by road from the study area.

3.4.2 Patient identification

After collecting and analysing the arsenic data, I asked a local medical doctor to identify arsenic-affected patients. This local physician had had a two-week long training on arsenic issues. I identified the users of high and severe arsenic contaminated tubewells and he then diagnosed 67 patients. I was sceptical of his diagnoses because, due to the infections from the contaminated flood-water, a considerable number of people, especially children, were found to be affected with skin lesions.

A major issue in the arsenic field in Bangladesh is that of the faulty diagnosis of arsenicosis patients. Several NGOs are employed in a donor-aided drive to check tubewell water and to identify arsenicosis patients, but the Dhaka Community Hospital (DCH) has exposed many misdiagnosed results. For instance, the Grameen Bank, a Bangladesh NGO, identified 48 arsenicosis patients in Kachua of Bagerhat district; while the DCH found only one of these to be affected with arsenicosis. In Manikganj, a local NGO diagnosed 72 patients, but the DCH found only two after rechecking the patient lists provided by that NGO (www.bangla2000.com/..../6-24-2000/news_detail1.html). I approached a second medical doctor having had experience of arsenicosis diagnosis. Accordingly, he identified 8 patients out of the previously diagnosed 67 patients and also 3 other patients outside the list. This physician identified these patients as having health conditions at different stages of arsenicosis.

3.4.3 Other quantitative data

The questionnaire survey was conducted during the screening of each tubewell (APPENDIX - B). A total of 375 questionnaire surveys – one for each tubewell holder were conducted. The questionnaire mainly addressed the basic issues of (a) the tubewell information; (b) household and health information; (c) social information and social problems; (d) alternative sources of drinking water; and (e) possible mitigation options.

The tubewell information comprised the installation year, depth, number of users etc. The household data covered the demographic information of the respective respondents. The societal data was about family problems (i.e. problems in conjugal life, divorce, separation, problems in getting married for young unmarried women etc.) and the social problems due to arsenic poisoning were also collected through this questionnaire survey. Where available, clinical and/or health databases of arsenicosis patients in different stages, age groups, occupation categories, and income groups as well as different social classes were collected as a further indicator of the impact of arsenic pollution.

3.4.4 Spatial data

For spatial analysis and mapping, GIS supporting data were collected during the field survey. The data used here for the compilation of a GIS are for spatial arsenic magnitudes. The spatial data address the point, line and polygon information of tubewells and related parameters. The spatial data were collected from primary and secondary sources. All the tubewells in the study area were plotted on *mauza* maps with different tubewell identification numbers. Settlement areas, ponds, different road networks etc were also plotted. In addition, many point features apart from the tubewell location, *union* headquarters, growth centres, health complex, family planning centre, schools, etc were recorded as components of zero length. The collected spatial data were digitised and entered in a GIS format (ArcGIS).

The inserted spatial data layers in the GIS were edited by removing errors (arc, node and label error) and then these corrected data layers were shifted into PAT (Point or Polygon Attribute Tables) and AAT (Arc Attribute Tables) topologies for analysis. Various point, line, and polygon features were transformed into real world co-ordinates through a Lambert's Projection Programme for the sub-tropical zone. Using GIS analytical techniques, the following questions were answered:

(a) How many tubewells are safe and how many are contaminated?

(b) Which aquifer is safe and which aquifer is contaminated? and

(c) How many people use water from different tubewells?

3.5. QUALITATIVE RESEARCH and DATA COLLECTION

Qualitative research is especially useful for the exploration and discovery of inherent social problems. Generally, qualitative research may be defined as an attempt to obtain an in-depth understanding of the meanings and 'definitions of the situation' (Wainwright, 1997) presented by informants, rather than the 'quantification' (Strauss and Corbin, 1998) of their characteristics. Qualitative analysis was used to uncover and understand what lies behind arsenic poisoning in health and social concerns in which little is yet known, for instance, the intricate details of phenomena that are difficult to convey with quantitative methods (Strauss and Corbin, 1998). In qualitative research, knowledge and theory are generated from empirical data (Bunne, 1999). Qualitative research, according to Rich and Ginsburg (1999) can be defined as:

> ". . . . Qualitative research is an ideal approach to elucidate how a multitude of factors such as individual experience, peer influence, culture, or belief interact to form people's perspectives and guide their behaviour" (Rich and Ginsburg, 1999).

Qualitative research examines the complex social world, especially meanings and behaviours in a social context (Powell and Single, 1996; and Rich and Ginsburg, 1999). Qualitative inquiry is an umbrella term for various philosophical approaches to interpretive research (Eisner, 1991 and Glesne and Peshkin, 1992). Qualitative methods generate detailed and valid data with multiple forms of evidence (Eisner, 1991) that permit formulation of new hypotheses and inform further study or practice (Bunne, 1999; Powell and Single, 1996; and Strauss and Corbin, 1990).

Qualitative methods for this thesis consist of field observations in the participants' natural environments, oral and written narrative, text, sounds, and visuals. This qualitative study used more than one type of data collection technique to enrich and add perspective to the pool of information on arsenic inquiry. Qualitative research methods were mainly designed to understand the lives of arsenic-affected people and their social and health issues. The qualitative data collection methods for this thesis were made by means of PRA techniques, participant observations, and ethnography, as well as interview techniques in terms of informal dialogues, in-depth interviews, and focus-group discussions. The in-depth interviews and focus-group discussions were tape-recorded with permission. In addition, photographs were used for collecting observations. The questions addressed to the arsenic and related issues were open in order to get rich information including variation of findings.

3.5.1 The PRA methods

PRA is "an alternative and complementary technique to conventional sample survey methods" (Mukherjee, 1995a) for learning about "rural life and conditions from, with and by rural people" (Chambers, 1995). It is one of the many approaches that helps to turn a theoretical and important awareness into reality (Bell, 1996; Binns *et al*, 1997; Chambers, 1994; Fals-Borda, 1998; Loader and Amartya, 1999; and Wilson, 1997). The definition of PRA highlights a paradox. It is the 'people-oriented' (Richards, 1995) dimension in development/planning and is becoming a routine demand in qualitative research (Guijt and Cornwall, 1995). PRA is a powerful approach for providing information, feedback and recommendations to experts and policy makers at the micro-level, as well as a method of systematic and quick collection for the general analysis of a particular issue.

The PRA method was developed in the late 1980s (de Koning, 1995) with some modifications of the RRA (Rapid Rural Appraisal) method (Chambers, 1997). During recent years, there has been increasing emphasis on the PRA rather than RRA (Whiteside, 1997). PRA approaches are useful and effective for exploring rural issues in a rapid and more cost-effective manner (Gill, 1991; Hildebrand, 1981; and Honadle, 1982). The method is used to "obtain a differentiated understanding of the community's attitudes, beliefs and behaviours" (Mukherjee, 1995a) towards an issue or problem.

PRA is an umbrella term for a wide variety of applications with a range of choices of different techniques that could be used individually or in any combination. It is widely described as an approach, a process, a methodology, an activity, a technique, a basket of tools or a menu of methods (Guijt and Cornwall, 1995). Without local knowledge, local information, local insights and qualitative information, as well as indigeneous knowledge and communal wisdom, it is difficult to make any conclusion about the impact of arsenic on health and social issues of arsenic-affected people. The most immediate use of the PRA is for problem identification. It needs to be complemented by critical reflection on events to generate information on local social relationships (Mosse, 1995).

In this thesis, PRA methods have been used to gain an initial impression of arsenic problems in the study area. They allowed me to gather general data on the local history of contamination and poisoning. Under a PRA conceptualisation, triangulation, reconnaissance survey, informal meetings with the local people etc were adopted in getting a quick picture of arsenic situation of the study area. On this basis, I slightly modified my previously selected research objectives and my study villages, i.e. I selected all the five villages of Ghona *Union*, and developed a plan for tubewell screening, formal and informal dialogues with the local people. I also made necessary contacts and prepared the ground in each community in terms of what my activities were about.

3.5.2 In-depth interviews

In-depth interviewing is defined as ". . . a social relationship . . . a short-term, secondary social interaction between two strangers with the explicit purpose of one person obtaining specific information from the other" (Neuman, 1994). In the qualitative approach, interviewing is a highly personal process where meanings are created through personal interaction (Chen and Hinton, 1999 and Holstein and Gubrium, 1995). Where quantitative research is unhelpful or depth required, the in-depth interview becomes one of a small range of tools available to the researcher (Chen and Hinton, 1999).

In-depth interviews typically occur with individuals. This is a one-to-one research technique in which a respondent answers the questions of a researcher.

Different questions were asked of individuals (Appendix-D) for getting their understanding about the issue addressed on arsenic poisoning. Some 23 in-depth interviewees were selected from the study area for this thesis, of whom 11 were arsenic-affected patients (Table 3.4).

Table 3.4
Structure and composition of respondents for in-depth interviews

Cluster groups	Initial invitation	Number of respondents	Non-response error (%)
All patients	11	11	0
<0.05 mg/l	4	2	50
0.05-0.1 mg/l	4	3	25
0.1-0.3 mg/l	4	3	25
>0.3 mg/l	4	4	0

Data Source: Field survey, 2001.

The in-depth interviews were based upon open-structured questions so that a long-discussion would be possible in each interview. An interviewee was first asked some general questions regarding arsenic issues and afterwards I tried to ask him/her more questions concerning some relevant issues about arsenic in order to explore their views and ideas about social problems of the local arsenic-affected people and their health conditions. In addition, different NGOs and Government organisations that were working on the mitigation options of arsenic pollution were asked questions relevant to the arsenic mitigation and their policy responses.

3.5.3 Focus-group discussions

Generally, a 'focus-group discussion' refers to a specific form of group interview. It is a group of individuals selected and assembled by researchers to discuss the research topic (Krueger, 1988; Moore, 1987; and Stewart and Shamdasani, 1990). The focus-group method dates backs to the 1920s, when it was used as a market research technique (Powell and Single, 1996). As a technique of group interview, it has become an increasingly well-known method for collecting qualitative data. Morgan (1995) defines the focus-group method as "a research technique that collects data through group interaction on a topic determined by the researcher." The focus-group discussion technique employs an 'interaction discussion' (Powell and Single, 1996) as a means of generating "rich details of complex experiences and the reasoning behind actions, beliefs, perceptions and attitudes" (Carey, 1995). Focus-groups are frequently used to learn about the topics from local participants.

A focus-group is not just a way of collecting multiple individual statements, but is a means to set up a negotiation of meanings through intra and inter-personal debates (Cook and Crang, 1995). The focus-group discussion method was adopted in this thesis since the investigation of arsenic issues over health and social concerns was complex. In addition, sometimes, the results of quantitative survey are ambiguous or misleading and statistical associations require clarification, 'salvaging' (Powell and Single, 1996) or elaboration. In this respect, the focus-group method was employed to explore complex phenomena about arsenic related issues and to ensure the validity of data (Appendix-E).

Focus-group discussions are formal (Khan and Manderson, 1992) and are involved with inviting participants to join in the discussion. This can be achieved using theoretical sampling (Powell and Single, 1996). In designing a focus-group, I kept in mind the following issues:

(a) Who will participate in the groups?

(b) How structured will the groups be?

(c) How many groups should be established? and

(d) How many participants will be involved in each group?

A stratified random sample was chosen in selecting the participants, following the occupational homogeneity and sex segmentation procedure as a basis for invitation to discuss arsenic issues. Some 5 groups of different occupations were selected for discussing the arsenic issues after informal discussions with different local people (Table 3.5). The occupational homogeneity of focus-group composition was kept in mind. The participants of focus-groups were stratified according to these homogeneity and segmentation characteristics.

Table 3.5
Structure and composition of focus-groups for group discussions

Focus-groups	**Initial invitation**	**Number of participants**	**Non-response error (%)**
FG-1: Farmers	10	9	10
FG-2: School and Madrasa Teachers	12	8	33
FG-3: NGO & Health officials	18	7	61
FG-4: Political Leaders and Social Activists	12	10	17
FG-5: Elected Administrators	13	6	54

Data Source: Field survey, 2001.

The focus-group size is an important factor for the interview process. It is difficult to maintain an active discussion in a small group; while it is more difficult to manage discussions in larger groups. In practice, the group size for this study depended mainly on the number of groups by occupational homogeneity and gender segmentation (Figure 3.3).

The selection of a moderator in a focus-group is important for discussion. A moderator works to a non-perspective, semi-structured interview schedule and usually supplements the prepared questions with sub-questions. Scholars seem to vary in their views about focus-group composition; but I chose as follows:

(a) Participants with homogeneous characteristics, but systematic biases were avoided in selecting the participants;

(b) Relatively structured discussions; and

(c) 6-10 people participated in each focus-group, from the initially invited 10-18 people for each group, and 5 focus-groups were selected (Figure 3.4).

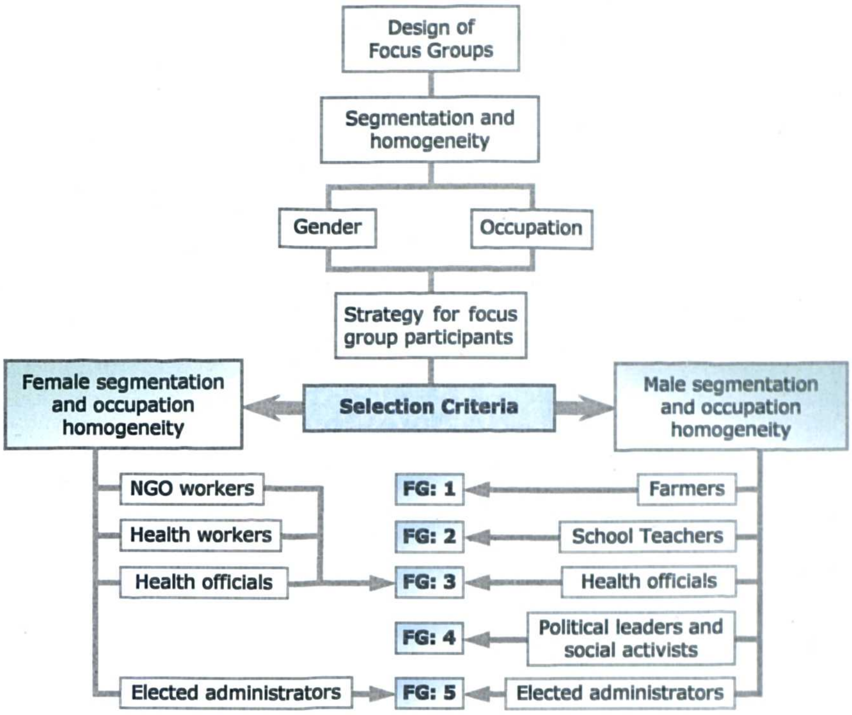

Figure 3.3: Selection criteria and composition of various focus-groups.

3.5.4 Participant observation

In-depth interviews and focus-group discussions along with the PRA methods provided valuable information regarding the arsenic issues, but participant observation enriched the collected database with other additional supporting information. This method helped me to 'cross-check' other databases collected using different qualitative methods.

A central objective of participant observation is to ensure that the voices of arsenic-affected people and ordinary people in the study area could figure prominently in the dialogue. Ordinary people are frequently regarded as unimportant, ignorant, tradition-bound and inactive, although in reality they may make sizeable contribution to the development of their country (Kyei, 2000).

Figure 3.4: Five selected focus-groups for group discussion.

During my visits to every tubewell, I observed people's opinions about many issues concerning arsenic poisoning. Apart from the everyday morning breakfast with the local people and playing *caram* with the local leaders in afternoon sessions, as I mentioned in section 3.2, I communicated with many local people very closely and participated in different informal discussions with them. This free and frank mixing was helpful to gather different dimensions of social data.

I observed how people collect water from different tubewells including arsenic-free water from deep tubewells and other safe tubewells. I also participated at evening gatherings during the periodic marketing days (two days in a week: Sunday and Thursday) and people provided me with their opinions concerning many relevant issues. At the beginning of my fieldwork, some had criticised my activities, but later, they appreciated my work. In the closing stages of my fieldwork, one man told me that, ". . . your work is an example of how to work honestly. We have seen many people undertaking development works, but your work is exceptional. Everybody in this village knows you and they know your work."

3.5.5 Participatory GIS analysis for map data

Traditionally, GIS has been considered to represent a top-down and technology-driven approach in spatial decision-making processes. Conventional GIS focuses on the digital representations of social and environmental phenomena that best reflect their 'expert viewpoint' (Weiner *et al*, 1995) rather than on lay perceptions.

GIS is a computer-based technology for integrating spatial and non-spatial information into a common environment for spatial analysis, mapping output and graphic display as well as spatial decision-making. In recent times, GIS with its 'unique analytical capabilities' (Wood, 1993) in representing spatial information, has faced criticisms that it has concentrated on the 'easy equation' (Harris *et al*, 1995) of environmental investigations rather than socio-cultural analysis. In addition, GIS has also been accused of reinforcing top-down expert analysis rather than addressing the bottom-up approach[2] to development issues. The PGIS techniques have been developed to integrate local people's perceptions and to analyse their knowledge as part of the 'participatory development' (Abbot *et al*, 1998) and for future spatial decision-making as the representation of 'multiple realities for single uses' (Cinderby, 1999). Abbot *et al* (1998) commented on the conceptual framework of PGIS:

> ". . . . Participatory GIS draws on the diversity of experiences associated with 'participatory development' and involves communities in the production of GIS data and spatial decision-making. . . . local people could interpret output from a GIS or contribute to it, such as by integrating participatory mapping information to modify or update a GIS" (Abbot *et al*, 1998).

Maps can be seen to represent a more universal visual language and the maps produced by participatory techniques and integrated with GIS demonstrate the local conditions more accurately. Maps, in this regard, can investigate the impacts in a more insightful way than conventional questionnaire survey techniques. Cinderby (1999) regarding this situation argues that:

> ". . . . The potential of incorporating a participatory approach within a GIS appears to offer a solution to the criticisms levelled at conventional 'top-down' spatial analysis. These include the undemocratic nature of GIS analysis and the representation of single agency solutions to multiple reality issues" (Cinderby, 1999).

The combination of spatial database and perceptual mental maps facilitates a greater shared understanding of local problems. The PGIS technique allows multiple viewpoints to be accommodated within a single frame of reference. The PGIS techniques have been given different names in different areas, such as, 'public forum GIS' (NCGIA, 1998), 'public participation GIS' (Harris *et al*, 1995), 'community integrated GIS' (Harris and Weiner, 1998) and 'counter mapping GIS' (Rundstrom, 1998).

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2 The bottom-up approach is recognised as an appropriate strategy for meeting the needs of the poor as against the top-down strategy, which has limited linkage-effects and impact on poverty eradication (Stohr, 1981).

The PGIS approach builds upon existing PRA concepts. In PGIS, local people conduct their own analysis and develop their own strategy. A PGIS "attempts to promote a 'bottom-up' policy of development by incorporating local concerns and knowledge within a spatial database" (Cinderby, 1999). The use of mental mapping[3] at the grass-roots level prepared by different local community people within a framework of conventional participatory analysis could reflect the existing local arsenic conditions in the study area.

Wider public acceptance of the results of GIS-based decision-making through a PGIS process is an important aspect of this thesis. The conventional top-down expert-produced GIS data were integrated with local level participatory analysis. The incorporation of different mental maps into a digital spatial database allows the use of conventional GIS techniques to achieve a greater understanding of the planning of safe tubewells in the study area. By overlaying different mental maps within the conventional GIS environment, I have been able to demonstrate the need to install deep tubewells in the study area for arsenic-free water. The combination of different datasets has enhanced the understanding of both the local community and the 'expert' viewpoint.

3.6. DATA ANALYSIS

This section presents the different analytical methods of collected data for this thesis. The analysis of data consists of four linked processes (Silverman, 1993): (a) data reduction; (b) data display; (c) conclusion drawing; and (d) verification. The collected quantitative and qualitative data were analysed by different techniques. The quantitative data analyses were based on both statistical and

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[3] Mental or Cognitive mapping is a process by which an individual recalls and decodes information about the location and attributes of phenomena in their everyday environment (Fox, 1998). The production of such mental maps typically involves members of the local community drawing features of interest. The features selected for inclusion are dependent on the community groups with or without guidance from an outside facilitator (Cinderby, 1999).

spatial operations; while the qualitative modes of analyses were mainly hermeneutics, phenomenology, ethnography, discourse analysis, narrative analysis and the grounded theory approach.

3.6.1 Statistical analysis: generalised linear models

The quantitative data were analysed by statistical methods to address the research questions. Generalised linear models (GLMs) were mainly used to identify the pattern of association between different variables. GLMs are mathematical extensions of linear models that do not force data into unnatural scales, and thereby allow for non-linearity and non-constant variance structures in the data (Hastie and Tibshirani, 1990 and McCullagh and Nelder, 1989). Generalised linear modelling is a development of linear models to accommodate both non-normal response distributions and transformations to linearity in a clean and straightforward way (www.isds.duke.edu/computing/. . .) with a minimum of extra complication compared with normal linear regression. They are based on an assumed relationship (called a link function) between the mean of the response variable and the linear combination of the explanatory variables (Guisan *et al*, 2002 and Khuri, 2001).

GLMs were introduced by Nelder and Wedderburn (1972) as an extension of the class of linear models. In generalised linear modelling, models are fitted to data that follow several members of the exponential family of probability distributions (e.g. normal, gamma, possion, binomial, negative binomial, multinomial, etc), many of which better fit the non-normal error structures of arsenic data (Yee and Mackenzie, 2002). Thus, GLMs are more flexible and better suited for analysing ecological relationships, which can be poorly represented by classical Gaussian distributions (Austin, 1987).

Hypothesis tests applied to the GLM do not require normality of the response variable, nor do they require homogeneity of variances (Khuri, 2001). The maximum likelihood estimation technique is an important advent in the development of GLMs (Nelder and Wedderburn, 1972; McCullagh and Nelder, 1989; Harrell, 2001; Hastie *et al*, 2001; and Smyth and Verbyla, 1999). Estimation of regression coefficients in GLMs is performed using the Newton-Raphson or Fisher-scoring algorithm (Yee and Mackenzie, 2002). The Newton-Raphson (maximum likelihood) optimisation technique was used for this thesis to estimate the GLM using STATA (version 7.0) software.

3.6.2 Spatial interpolation and geostatistics

Thematic maps were developed to define the pattern of arsenic magnitudes and its spatial variation by using spatial interpolation methods. Interpolation is the process of estimating the value of parameters at unsampled points from a surrounding set of measurements (Burrough and McDonnell, 1998). When the local variance of sample values is controlled by the relative spatial distribution of these samples, geostatistics can be used for spatial interpolation (Oliver and Khayrat, 2001). Point interpolation techniques were employed concerning the arsenic magnitudes over the space-time dimension.

The geostatistical approach relies on both statistical and mathematical methods, and can be used to create surfaces and assess the uncertainty of the predictions (Johnston *et al*, 2001). Geostatistics represent one of the most powerful procedures for producing contour maps for regionalised variables (Badr *et al*, 1993 and Beliaeff and Cochard, 1995). If the property varies continuously in geographical space, it can be regarded as a regionalised variable (Badr *et al*, 1993 and Oliver and Khayrat, 2001). The geostatistical approach can be described as the spatial variation of a property and, thereby, indicate an appropriate method of prediction (Oliver and Khayrat, 2001). Principal interpolation methods in describing the spatial arsenic magnitudes in this study are based on the Inverse Distance Weighting (IDW), Radial Basis Function (RBF) and Kriging methods.

Inverse Distance Weighting (IDW) Method: The IDW interpolator is a point estimation technique based on the weighting of a random function for a particular cell node of a grid (Serón *et al*, 2001). The IDW interpolator assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing cell greater than those further away, hence the name Inverse Distance Weighted (IDW) interpolation or Inverse Squared Distance (ISD) interpolation (Ashraf *et al*, 1997). In the IDW interpolation method, the maximum and minimum values in the interpolated surface can only occur at sample points (Johnston *et al*, 2001; Serón *et al*, 2001; and Longley *et al*, 2001). A specified number of points, or all points within a specified radius, can be used to determine the output value for each location. The IDW interpolation method can be calculated using the following equation (Johnston *et al*, 2001):

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (3.1)$$

Where, $\hat{Z}(S_0)$ is the prediction value for location, S_0, N is the number of measured sample points surrounding the prediction location, λ_i is the weight assigned to each measured point, and $Z(S_i)$ is the observed value at location S_i. But, in determining the weights, the following formula option is used (Johnston *et al*, 2001):

$$\lambda_i = d_{i0}^{-p} \Big/ \sum_{i=1}^{N} d_{i0}^{-p} \qquad \sum_{i=1}^{N} \lambda_i = 1 \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (3.2)$$

As the distance becomes larger, the weight is reduced by a factor of p. The quantity d_{i0} is the distance between the prediction location, S_0, and each of the measured locations, S_i.

In the IDW method, the surface is driven by local variation. The surface calculation using the IDW method depends on the selection of: (a) a power parameter; and (b) the neighbourhood search strategy. The power parameter in the IDW method controls the influence of the surrounding points upon the interpolated value. A higher power results in less influence from distant points (Tsanis and Gad, 2001); while the optimal power value is determined by minimising the root-mean-square prediction error (RMSPE). If the power value is

0, there is no decrease with distance. The RMSPE is a summary statistic quantifying the error of the prediction surface. It is better to use the power value >1, while the power value of 2 is known as the inverse distance squared weighted interpolation (Johnston *et al*, 2001; Serón *et al*, 2001; and Tsanis and Gad, 2001).

The searching neighbourhood in the IDW method defines the neighbourhood shape and the constraints of the points within the neighbourhood that are used in prediction of an unmeasured location (Johnston *et al*, 2001). The shape of search neighbourhood is based on an understanding of spatial locations and the spatial autocorrelation of the dataset. If the collected data is not spatially evenly sampled and has "no directional autocorrelation" (isotropy), the neighbourhood shape will be specified to be a circle; while in "any directional autocorrelation" (anisotropy), an elliptical search neighbourhood scheme is used for interpolating a surface (Johnston *et al*, 2001). Once shape is defined, the second mechanism for controlling the neighbourhood involves establishing constraints within the shape (Johnston *et al*, 2001). Generally the search area of the IDW method is a circular weighting, but the area could be elliptical or even directional in order to remove the strong influence of local anomalous values due to clustered data surrounding the estimation point (Carrat and Valleron, 1992; Beliaeff and Cochard, 1995; Isaaks and Srivastava, 1989; and Serón *et al*, 2001).

In producing the prediction maps for spatial arsenic magnitudes, I specified the power function and search neighbourhood in the interpolation. By using the modified power value of 2 (where the optimise power value was 1.5911) with 40 input neighbours (5 neighbours include at least 2 in 8 angular sectors) in an elliptical neighbourhood shape having 330^0 axis angle from a test location (X: 2637966 and Y: 552476), the IDW interpolation map for spatial arsenic magnitudes was produced.

Radial Basis Function (RBF) method: The RBF method is formed over each data location and is a function that changes with distance from a location (Johnston *et al*, 2001). It is a form of artificial neural network (Johnston *et al*,

2001) and in this interpolation technique, the surface passes through all of the measured data values (Johnston *et al*, 2001 and Tsanis and Gad, 2001). The method is conceptually similar to fitting a rubber membrane through the measured sample values while minimizing the total curvature of the surface (Johnston *et al*, 2001; Tsanis and Gad, 2001; and Beliaeff and Cochard, 1995).

The RBF method can predict above the maximum and below the minimum measured values (Johnston *et al*, 2001). It is used for calculating smooth surfaces from a large number of data points. The function produces good results for gently varying surfaces of any parameter or object, but is not appropriate when there are large changes in the surface values within a short horizontal distance because it can overshoot estimated values when the sample data is prone to error or uncertainty (Serón *et al*, 2001; Franke, 1982; and Johnston *et al*, 2001). The method can extrapolate values beyond scattered data point values and local anomalies cannot be seen with low order polynomial surfaces (Serón *et al*, 2001). The RBF method does not allow us to investigate the autocorrelation of the data and it makes no assumptions about the data (Johnston *et al*, 2001).

In producing the surface to form smooth curves for the spatial magnitudes of arsenic over space, I used the 'thin-plate spline RBF method' for its 'smoothness' of the surface (Franke, 1982). This thin-plate spline method enables us to create a surface that captures global trends and picks up the local variation. It works well in cases where fitting a plane to the sample values do not accurately represent the surface.

In producing the prediction maps for spatial arsenic magnitudes, I specified the power function and search neighbourhood in the interpolation. By using the optimised power value of 2 with 40 input neighbours (5 neighbours include at least 2 in 8 angular sectors) in an elliptical neighbourhood shape having 330^0 axis angle from a test location (X: 2637966 and Y: 552476), the RBF prediction map using the thin-plate spline method was produced.

Kriging interpolation method: Kriging is a stochastic and optimal point interpolation method for the unbiased estimation of field variables (Isaaks and Srivastava, 1989; Oliver and Khayrat, 2001; Patgiri and Baruah, 1995; Phillips and Marks, 1996; Rizzo and Dougherty, 1994; and Tsanis and Gad, 2001). The method is based on the theory of regionalised variables whose values vary from place to place (Davis, 2002; Kalabokidis and Omi, 1995; and Persicani, 1995) and the method relies on the notion of autocorrelation between variables (Petkov *et al*, 1996; Serón *et al*, 2001; and Wang *et al*, 2001).

Kriging is a means of local estimation in which each estimate is a weighted average of the observed values in the neighbourhood (Patgiri and Baruah, 1995 and Söderström and Magnusson, 1995). It is a collection of generalised linear regression techniques and is a distance weighting estimation method that takes into account the spatial characteristics of the local structure through the variogram function (Davis, 2002 and Serón *et al*, 2001). The kriging method provides the local details about the spatial variation of a property (Oliver and Khayrat, 2001). It derives in the name from DG Krige, who introduced the use of moving averages to avoid systematic errors in interpolation (Krige, 1976).

The first step of the kriging method involves modelling the spatial structure of the regionalised variable of considerable arsenic concentrations over the study area. The kriging treatment quantifies this variation in the form of semivariogram, which graphically expresses the relationship between the semivariance and the sampling distance (Persicani, 1995; Brooker *et al*, 1995; and Mapa and Kumaragamage, 1996). The semivariogram, $\gamma(h)$, is half the average squared difference between pairs of data $Z(x_i)$ and $Z(x_i+h)$, separated by a given distance h (lag). An estimate of semivariogram with $N(h)$ the number of sampling pairs separated by a distance of h is given by the following equation (Lacaze *et al*, 1994):

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\{Z(x_i+h)-Z(x_i)\}^2 \quad \ldots\ldots \quad (3.3)$$

The nugget variance, range and sill of each semivariogram are the parameters providing the basis for interpretation of spatial dependence (Journal and Hujibregts, 1978). The semivariogram for the arsenic data illustrates a number of common features (Petkov *et al*, 1996 and Gerlach *et al*, 2001): (a) $\gamma(h)$ increases from smaller to larger lags but a limiting 'sill' is always found; (b) $\gamma(h)$ approaches the small lags, suggesting a large 'nugget effect'; and (c) the spherical semivariogram model gives good and acceptable fits to $\gamma(h)$.

In the second step of kriging, the selected model of spatial structure is applied to the data set to predict values at unmeasured sites i.e. to fit a model to the experimental data. The type and shape of the variogram determines the weights λ_i needed for local interpolation in the kriging process. Linear, spherical, or exponential models are generally used to fit the variogram (Webster, 1985), but a frequently used model is the spherical (Brooker *et al*, 1995). In this thesis, arsenic interpolation map produced by kriging method was constrained by spherical semivariogram fit. The experimental variogram was computed from the raw arsenic data and a mathematical model (Brooker *et al*, 1995; Mapa and Kumaragamage, 1996; and Persicani, 1995) was fitted to the arsenic values by weighted least-squares approximation, using the geostatistics of ArcGIS. The spherical model (3.6) was used to fit the raw semivariogram (Chang *et al*, 1998).

$$\left\{\begin{array}{ll}\gamma(h) = C_o + C_1\left[\dfrac{3h}{2a} - \dfrac{1}{2}\left(\dfrac{h}{a}\right)^3\right] & \text{as h} \le \text{a} \\ \gamma(h) = C_o + C_1 & \text{as h} \ge \text{a}\end{array}\right\} \quad . \; . \; . \; . \; (3.4)$$

where, C_o is the nugget variance, and the lag, h required to reach the sill ($C_o + C_1$) is called a range, a. The function was evaluated in the SE-NW direction (there are four different directions: N-S, E-W, NE-SW, SE-NW) to identify the anisotropic variation present in the study area. The kriged value of a regionalised variable, $Z^*(x)$, of an unobserved point at location x is predicted by a linear combination of the values of n surrounding data points,

$$Z^*(x)=\sum_{i=1}^{n}\lambda_i Z(x_i) \quad \ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

Where, $Z(x_i)$ is an observed value and λ_i is the weight of *i*th neighbouring value which minimise the error variance. Kriging estimate is known as the **b**est **l**inear **u**nbiased **e**stimate (BLUE), because it is a linear combination of the weighted sample values, whose expected value for error equals zero and whose variance is a minimum (Caruso and Quarta, 1998 and Isaaks and Srivastava, 1989). Ordinary Kriging was used in this study since arsenic concentrations in groundwater are highly uneven. Ordinary Kriging is the most widely used type of Kriging to estimate values when data point values vary or fluctuate around a constant mean value (Serón *et al*, 2001). It was applied for an unbiased estimate of spatial variation of arsenic concentrations in the study area.

In producing the prediction maps for spatial arsenic magnitudes by the Ordinary Kriging method, I specified the semivariogram and search neighbourhood in the interpolation. By using the spherical semivariogram having the nugget value of 0.0075363, with 20 input neighbours (5 neighbours include at least 2 in 8 angular sectors) in an elliptical neighbourhood shape having 330^0 axis angle and 0% measurement error from a test location (X: 2637966 and Y: 552476), the kriging prediction map was produced.

3.6.3 Spatial GIS analysis

Spatial GIS methodologies were used to figure out arsenic concentrations in the groundwater. GIS modelling involves a symbolic form of representation (abstract representation) of locational properties (where), as well as thematic (what) and temporal (when) attributes describing characteristics and conditions of the arsenic magnitudes in the space-time dimension. This spatial analysis is an expression of the mathematical relationships among mapped variables concerning arsenic issues. The spatial analyses were mainly composed of spatial data editing and transformation, attribute database creation and manipulation, and data analysis and interpretation, in performing geographical analysis in terms of overlay operations to identify spatial patterns of arsenic magnitude and buffer generation for mapping the proximity area of arsenic concentrations. In addition, reclassification and measurement operations were used for GIS mapping and data analysis.

Reclassification and measurement operations: Reclassification operation refers to the transformation of attribute information associated with a single map layer. It represents the 'recolouring' of features in the map (Martin, 1991). A map of arsenic contamination in tubewells for the study area may be classified into classes such as 'safe tubewells' and 'contaminated tubewells' without reference to any other information. Besides, tubewell ownership can be categorised as 'private', 'government', 'NGO' or 'community' tubewells without other attributes. Measurement operation was used for calculating the distances between tubewells and different points, lengths of lines, as well as perimeter of 'safe zones' and 'risk zones'.

Buffer generation: Buffer is a form of proximity analysis around coverage features (Berry, 1987; Densham, 1991; and Rahind, *et al*, 1984). This operation involves the identification of spheres of influence or sphere zones of shallow tubewells and deep tubewells in the study area. The spatial 'risk zones' of arsenic have been measured by the buffer zones of different point, line and polygon features, deducting them from the settlement area (Figure 3.5).

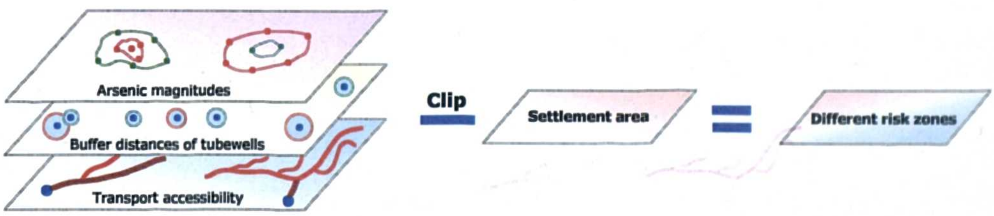

Figure 3.5: Buffer distances and overlay operation.

The 'risk zones' and 'safe zones' have been identified by using the buffer generation for contaminated tubewells and safe tubewells. In this case, buffer distances of each tubewell were calculated according to people's perceptions about the threshold limit (the maximum distance in which people can collect water from a tubewell). The threshold limit or influence zone was identified during my field survey in 2001.

In addition, different buffer distances of different surface water bodies were measured to identify what amount of land of each buffer distance can be used for irrigation to switch over the use of groundwater. The distance between nearest tubewell in the study area have also been identified by buffer distances of sample tubewells.

Overlay operation: The overlay operation is a suitable technique to perform spatial analysis in GIS. This operation is the process of integration of two or more data layers (Martin, 1991) and may result in the delineation of new boundaries. In overlay operation, area features on one data layer are overlaid on to those of other data layers in order to calculate areas which have a certain combination of attributes. For instance, overlaying the settlement area and arsenic magnitudes data layer provided information of arsenic 'problem regions' in settlement areas of the study area. This operation provided information for identifying low to high arsenic risk zones in performing map feature integration of point-in-polygon, line-in-polygon and polygon-in-polygon georelational topological data structure. To measure arsenic magnitudes zones or arsenic risk zones, various PC ArcGIS OVERLAY techniques have been used. The UPDATE technique has been used for the coverage updating; CLIP has been used for feature and coverage extraction; ELIMINATE and DISSOLVE for feature merging of various coverages; and IDENTITY for spatial join for various data layers (ESRI, 1995).

3.6.4 Qualitative modes of analysis

Qualitative modes of analysis recognise the primacy of the subject of inquiry (Rich and Ginsburg, 1999). The qualitative analysis for this thesis is based on the interpretation of text and observations. The qualitative data are analysed from multiple perspectives using different analytical methods (Miles and Huberman, 1994; Silverman, 1993; and Wolcott, 1994). Some modes (e.g. thick description) of analysis consider the data to be present without interpretation and abstraction (Geertz, 1973); some modes (i.e. ethnography, action research and pattern analysis) consider to creating a "rich descriptive narrative" (Strauss and Corbin, 1998) and vivid presentation of new understanding; and some (i.e. phenomenology, grounded theory, and discourse analysis) seek to build new understanding and theory using high levels of interpretation and abstraction (Bunne, 1999; Rich and Ginsburg, 1999; and Strauss and Corbin, 1998). This thesis aims to combine some of these approaches for exploring and presenting rich descriptive narratives by developing new concepts of arsenic toxicity.

3.6.3.1 Hermeneutical approach

The hermeneutical approach refers to a process of making sense of a written text for people in a situation, i.e. the people's story not the author's (Ratcliff, 1999). As a philosophical approach to human understanding, it provides the philosophical grounding for interpretivism; while as a mode of analysis, it suggests a way of understanding textual data (Bleicher, 1980 and Myers, 1997). Hermeneutics is primarily concerned with the meaning of a text or text-analogue (Myers, 1997 and Ratcliff, 1999), i.e. what is the meaning of this text. In this analysis procedure, the hermeneutical aspect was dealt with the holistic[4] approach.

The interpretation of the meaning of human expressions, hermeneutics, is fundamental in qualitative research (Boland and Day, 1989; Boland, 1991; Bunne, 1999; Lee, 1994; and Myers, 1994). Historically, hermeneutics emanates from the interpretation of Bible texts and it emphasises an interpretative element in analysis (Bunne, 1999). Ricoeur (1974) suggests that "interpretation

4 Holistic approach: It is a wide-reaching term, designating views in which the individual elements of a system are determined by their relations to all other elements of that system (http://www.counterbalance.org/gengloss/holist-body.html). Holistic theories claim that no element of a system can exist apart from the system of which it is a part.

. . . is the work of thought which consists of deciphering the hidden meaning in the apparent meaning, in unfolding the levels of meaning implied in the literal meaning". According to Taylor (1976):

> ". . . . Interpretation, in the sense relevant to hermeneutics, is an attempt to make clear, to make sense of an object of study. This object must, therefore, be a text, or a text-analogue, which in some way is confused, incomplete, cloudy, seemingly contradictory - in one way or another, unclear. The interpretation aims to bring to light an underlying coherence or sense" (Taylor 1976).

There are different forms of hermeneutical analysis - from 'pure' hermeneutics through to 'critical' hermeneutics (Bleicher, 1980; Palmer, 1979; and Thompson, 1981). Most qualitative analysis displays verbatim quotations, and there is rarely a discussion of how particular quotations are selected for presentation from the range of available interview texts (Baxter and Eyles, 1997). In this thesis interview conversations for qualitative research were constructed into theoretical concepts. Hermeneutical analysis in this thesis is used to make sense of the whole, and the relationship between arsenic-affected people and their real situation.

3.6.3.2 Discourse analysis

Discourse or critical analysis is to gain a comprehensive view of the 'problem' [www.lexus.gslis.utexas.edu/.../discourse.htm]. It is meant to provide awareness of the hidden motivations and, therefore, enable us to solve concrete problems (Ratcliff, 1999). Discourse analysis can be characterised as a way of approaching and thinking about a problem. It does not provide absolute and tangible answers to a specific problem, but it enables us to access to the ontological and epistemological assumptions behind a specific problem. Crush (1991) pointed out that discourses always provide 'partial' and 'situated' knowledges.

Since discourse analysis is an interpretative and deconstructive reading, there are no specific guidelines to follow, but use of the theories of critical and post-modern thinkers could be helpful. In short, discourse analysis reveals what is going on behind our backs and those of others and which determines our actions. During my fieldwork, I asked the same questions of the same people many times concerning my research objectives, and got different answers at different times. But, I gained insights based on continuous debate and argumentation with the local people. There is always remaining an element of interpretation. As there is no hard data provided through discourse analysis, the reliability and the validity of this research depends on the quality of rhetoric.

3.6.3.3 Narrative approach

The narrative approach refers to the process of understanding human motivations, perceptions, and behaviour by interpreting the stories people tell of themselves and their experiences (Atkinson, 1998; Bochner, 1997; Cortazzi, 1999; Reisman, 1993). It is the study of individual's speech (Ratcliff, 1999) and the method is mainly dealt with the naturalistic approach. It is the analysis of a chronologically told life story (Rybacki and Rybacki, 1991), with a focus on how elements are sequenced (Sillars, 1991).

A narrative is said to have a function that can reveal someone's experiences, proposed in various links to real events or real people. Narrative analysis is predominantly employed in discovering regularities (Mishler, 1995). This analysis, in conjunction with existentialism, enables interpretation of human existence (Hupet *et al*, 1998 and Naudin *et al*, 1995).

There is no agreed-upon methodology in narrative analysis to derive themes from patterns of situations. In this approach, the story is what a person shares about the self i.e. the aim of this approach is to compare ideas about the self. Narrative analysis is best used for exploratory purposes and a common focus is the exploration of ethical, moral, and cultural ambiguities. In some cases for this thesis, the in-depth interview data were analysed and interpreted with the narrative approach to get real understandings about the regular lives of arsenic-affected people.

3.6.3.4 Ethnographic representation

Ethnography seeks to understand the world as it is seen "through the eyes" (Kitchin and Tate, 2000) of the participants. It comes from the anthropological tradition and is concerned with the study of culture (Grbich, 1999). It refers to the process of studying people through the nature of their social structures and behaviours (Hammersley and Atkinson, 1995) in getting a more descriptive, explanatory approach (Hodgson, 2000). It is the work of describing a 'culture' (Lankford, 2000 and Spradley, 1980). Philosophically, ethnography falls within the emic and from a methodological perspective, it utilises unstructured interviews, and differing levels of observation, ranging from simple description to full participant observation (Kim, 1993). Ethnography rests within the naturalist approach rather than positivistic approach, in which the world should be examined in its "natural" state (Hodgson, 2000). The purpose of the ethnographic interview is to "discover cultural meanings which exist within a social group, emphasising interaction, social context, and social construction of knowledge" (Lowenberg, 1993).

Ethnographic representation is concentrated on the textual construction of reality. Fielding (1993) summarises a common approach to the ethnographic data analysis procedure (Figure 3.6). Harvey (1990) refers to the same process as 'pile-building'. In this thesis, the ethnographic data were first read 'vertically' i.e. in chronological order to identify common themes and relations, which were then coded. The data were then literally cut-up and re-ordered into 'piles' reflecting the key themes. The re-ordered data were then re-read, enabling a sequential argument to be constructed, and illustrative quotations from the transcripts were selected. Atkinson (1990) suggested that critical ethnography differs from traditional forms of qualitative

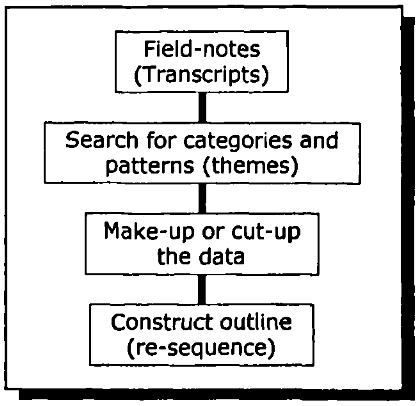

Figure 3.6: Ethnographic data analysis model (after Fielding, 1993).

data analysis, by bringing the broader critique of social relations to bear on the structuring of analytical themes.

3.6.3.5 Grounded theory approach

The grounded theory approach was used in this thesis for analysing qualitative data. The approach refers to the units of analysis, coding procedures and a rigorous notation in formulating a theory-development technique (Calloway and Knapp, 1995; Turner, 1983; and Kaplan and Duchon, 1988). When a theory is developed following the inductive method rather than deductive, it is called a 'grounded theory' (Glaser and Strauss, 1967). The approach is suitable for data collection, analysis (concept, property and category) and theory formulation in a reciprocal relationship (Baskerville and Pries-Heje, 1999 and Strauss and Corbin, 1998). Qualitative research with a grounded theory approach does not entail hypothesis testing as do quantitative studies. The research question in a grounded theory approach is a statement that identifies the phenomenon to be studied. Grounded theory questions tend to be oriented toward action and process (Strauss and Corbin, 1998).

During the 1950s and 1960s, social science research was dominated by the hypothetico-deductive model (Layder, 1982); while in late 1960s, Glaser and Strauss (1967) contrasted grounded theory with logico-deductive model to argue that the prevailing emphasis on theory testing neglected the process of theory generation. Grounded theory is now widely used in many of the social sciences and a methodological literature has developed to accompany its use (Annells, 1996; Barnes, 1996; Benoliel, 1996; and Strauss and Corbin, 1997).

Grounded theory refers to "an inductive, theory discovery methodology that allows the researcher to develop a theoretical account of the general features of a topic while simultaneously grounding the account in empirical observations or data" (Martin and Turner, 1986). The basic tenet of this approach is that a theory must be grounded in the data (Becker, 1993; Chamberlain, 1995; and Clarke, 1990). Grounded theory is considered to be particularly appropriate when little is known about a topic and there are few existing theories to explain a particular phenomenon (Hutchinson, 1988). The method is not conducted by logic but by the facts, i.e. the approach does not begin with theories, hypotheses or research questions like deductive methods; it begins with an area of study and allows the relevant theory to emerge from the qualitative empirical data (Eisenhardt, 1989 and Orlikowski, 1993).

The grounded theory approach, in this thesis was used as a form of field-study that systematically applied procedural steps to develop an explanation about the health and social aspects of the arsenic-affected people. The local people's perception concerning the impact of arsenic on their health and social conditions were fitted into a grounded theory approach in focussing on the realities of situation. The method was useful in developing context-based and process-oriented descriptions as well as explanations of the phenomenon (Orlikowski, 1993). In this thesis, the goal of grounded theory is to seek a new concept that is compatible with the field evidence concerning arsenic toxicity.

Grounded theory analytical elements: The three basic elements of grounded theory are concepts, categories and propositions (Figure 3.7). Concepts are the form of conceptualisation of data, not the actual data per se, upon which theory is developed (Pandit, 1996). Categories refer to the classifications of concepts i.e. groups of related concepts. The categories are characterised according to their location along various dimensions (Baskerville and Pries-Heje, 1999; Miles and Huberman, 1994; and Urquhart, 2000). Categories are "higher in level and more abstract than the concepts they represent. . . . Categories are the 'cornerstones' of developing theory" (Corbin and Strauss, 1990). The third element is propositions that indicate generalised relationships between a category and its concepts and between discrete categories. These were originally termed 'hypotheses' by Glaser and Strauss (1967). Since the grounded approach produces conceptual and not measured relationships, the former term is preferred. The generation and development of concepts, categories and propositions is an iterative process.

Coding and categorising: Data analysis in the grounded theory approach is involved in generating concepts through the process of coding and categorising (Stern, 1980). In grounded theory, coding represents the initial phase of the analytic method (de Búrca and McLoughlin, 1996 and Kerlin, 1998) and is a central process by which theories are built from data (Strauss and Corbin, 1998). Coding is a process of simultaneously reducing the data by dividing it into units or concepts of analysis, creating categories of concepts and coding each unit and categories (Calloway and Knapp, 1995 and (Miles and Hubermean, 1994). In the coding process, the collected data were broken down, conceptualised, categorised and sorted (Figure 3.7). The coding provided the pivotal link between data collection and its conceptual formation.

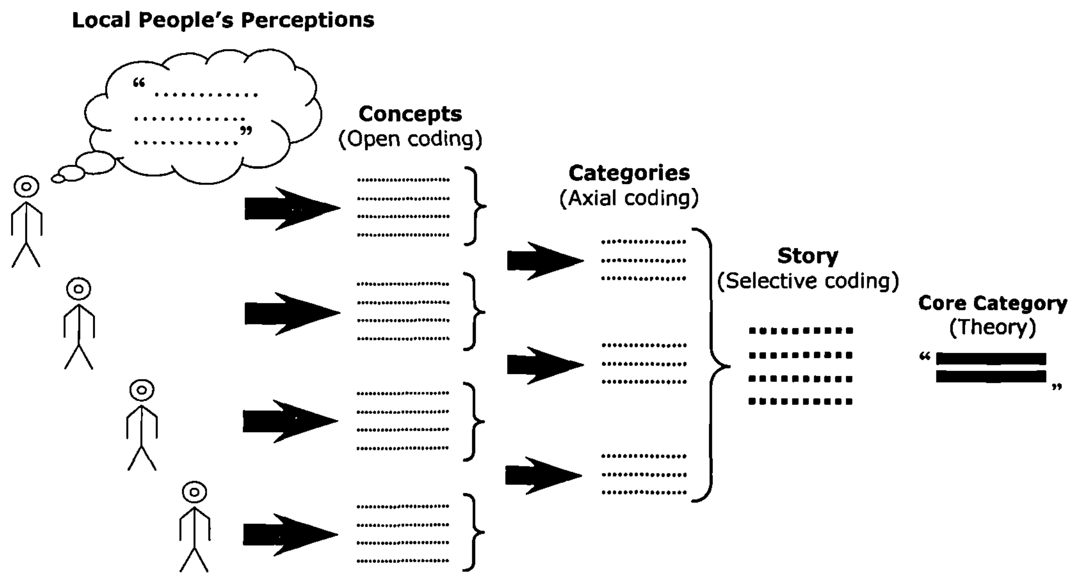

Figure 3.7: Coding Process in the Grounded Theory Approach.
(modified from Baskerville and Pries-Heje, 1999)

Glaser (1978) advocates <u>initial</u> coding followed by <u>focused</u> coding for the coding processes. At the beginning of the data analysis, the initial coding was used to separate, compile or summarise, synthesise, and sort the observations made of the data; while the focused coding was used to develop the coded data into different categories. The focused coding was used to build and clarify a category by examining all the data it covers and variations from it rather than simply to 'summarise large amount of information' (de Búrca and McLoughlin, 1996).

When a database is grouped or clustered into different forms or identities, categories created on the basis of conceptualisation of that data apparently relate to the same content. A natural creation of categories occurs with "the process of finding a focus for the analysis, and reading and annotating the data" (Dey, 1993). The analysis of data in the grounded theory approach is composed of three groups of coding procedures: (a) open; (b) axial; and (c) selective coding (Barrett *et al*, 1999; Hutchinson, 1988; Strauss and Corbin, 1998; and Urquhart, 2000).

Open coding refers to the labelling and categorising of phenomena as indicated by the data (Barrett *et al*, 1999; Pandit, 1996; and Thomas and Retsas, 1999). As the data were collected, I applied a system of open coding for looking at the database pattern and for identifying, naming and categorising the essential ideas found in the data. In this coding process a very shallow structure of initial categories was first set up, based on research questions and expected themes. This early structure then evolved as the actual themes developed in the data (Runge, 1997). In open coding, labelling is involved in decomposing an observation into discrete ideas and each discrete idea receives a name or label that represents the phenomenon (Baskerville and Pries-Heje, 1999; and de Búrca and McLoughlin, 1996 and Strauss and Corbin, 1998); while, category is the process of grouping the concepts that seem to pertain to the same phenomena (Baskerville and Pries-Heje, 1999). The process of grouping concepts at a higher, more abstract level is termed categorising (Pandit, 1996).

Axial coding refers to the process of developing the main categories and their sub-categories found in the open coding (Baskerville and Pries-Heje, 1999; Kerlin, 1998; Strauss, 1987; Strauss and Corbin, 1998; and Urquhart, 2000). This coding was used for understanding the relationships between various data categories that were determined during the open coding process. In axial coding, the sequence of relationships between connected categories and the validation of relationships in the data discovers the differences and similarities among and within the categories (Strauss and Corbin, 1998). This discovery adds the variation and depth of understanding that is necessary for selective coding (Baskerville and Pries-Heje, 1999). During axial coding, the application of the paradigm to the open codes examines the interaction aspects and the conceptualisation of the information system (conditions and consequences) can be thought of as emergent core categories (Urquhart, 2000).

Selective coding refers to the integration of the categories that have been developed to form the initial theoretical framework (Pandit, 1996). It is a process of selecting the core categories identified in the analysis. This coding process develops the theory that best fits the phenomena by identifying a story. A <u>story</u> is simply a descriptive narrative that reveals the central phenomenon (the main problem) under study i.e. a 'core category' emerges (Baskerville and Pries-Heje, 1999) and the <u>story line</u> is the conceptualisation of this story (abstracting). This story line becomes the core category and is defined as the central phenomenon around which all the other categories are integrated. According to Strauss and Corbin (1998) "the core category must be the sun, standing in orderly systematic relationships to its planets". The selective coding represents theoretical constructs derived from the data in combination with academic knowledge and knowledge acquired through praxis (Kerlin, 1998).

Theoretical sampling: Theoretical sampling is used in checking on the emerging conceptual framework rather than being used for the verification of preconceived hypotheses (Glaser, 1978) as well as to increase the depth of focus and to ensure that data are gathered in a systematic way for each category (Strauss and Corbin, 1990). Saturation is achieved when all the data fit into the established categories and no new categories emerge from the data (Kerlin, 1998). Theoretical saturation according to Glaser and Strauss (1967) occurs after many rounds of coding where no new categories emerge from the process. It is noted that effective theoretical development is greatly enhanced by theoretical sensitivity (Glaser, 1978 and de Búrca and McLoughlin, 1996). This theoretical sensitivity according to Strauss and Corbin (1990) refers to a "personal quality of the researcher."

Theoretical coding and memo writing: Theoretical coding is the process of data reduction through the theoretical sampling and the selective sampling (Glaser, 1978). Throughout the theoretical process of the literature, the core variable of the investigation emerges. What Glaser (1978) means by theoretical coding is how categories derived from the coded data are related to each other as hypotheses to be integrated into a theory. The core variable accounts for most variation in the data, and to which other variables appear to be related (de Búrca and McLoughlin, 1996). To this end integrating categories at a higher conceptual level means making a series of decisions (de Búrca and McLoughlin, 1996) and it is a question to decide whether the conceptual category reflects a significant process, relationships, event, or issue (de Búrca and McLoughlin, 1996).

An important activity during coding is the writing of memos (Glaser, 1978 and Pandit, 1996). According to Glaser (1978) "memos are the theorising write-up of ideas about codes and their relationships as they strike the analyst while coding". Since it was not possible to keep track of all the categories, properties, hypotheses, and generative questions that evolve from the analytical process, the memo writing system was adopted for doing so. A memo is the process for documenting the findings in a grounded theory investigation (Strauss and Corbin, 1998). It contains the coding products, summary notes, directions for further work, and records of concepts that are potentially sensitive in possible story lines.

Constant comparison method: The 'constant comparative method' of Glaser and Strauss (1967) is central to data analysis in generating grounded theory. Using this method, all the sample codes generated at each of the three levels are compared repeatedly within and between each other until the basic properties of a category or construct are defined. In addition, it is appropriate and desirable to compare the data categories and constructs that emerge between various groups of participants in the study.

This method develops conceptual categories from the data and then makes new observations to clarify and elaborate these categories (Frankfort-Nachmias and Nachmias, 1992). The coded data, in this process, are compared with other data and assigned to clusters or categories according to obvious fit (Glaser, 1978). In the constant comparative method, theory, data analysis and data generation are produced dialectically. This method requires continual revision, modification and amendment until all new units can be placed into an appropriate category (Dye *et al*, 2000).

The process of qualitative data analysis results is the least agreed upon and the least developed part of focus-group methodology (Carey, 1995). In this research, the in-depth interview and focus-groups data were analysed by the "constant comparison method" that corresponds closely to the data for most diversity of themes (Figure 3.8).

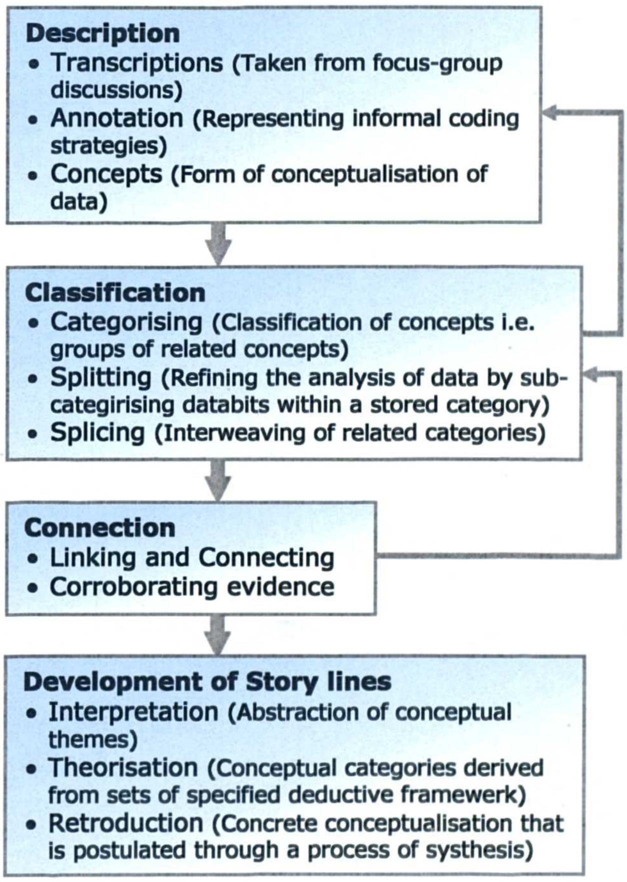

Figure 3.8: A general schema of qualitative data analysis.

The constant comparative method is able to identify the over-riding and integrating conceptualisations of higher order and lower order themes (higher order themes consist of theoretical arguments, which link the lower order themes together) in comparing incidents in each category and integrating categories with properties. This method allows the theory generated by the analysis to be grounded in the interview data and is not constrained by pre-defined, abstract categories.

3.7. LIMITATION: ERROR and ACCURACY

A number of limitations in terms of error and accuracy have been identified in different stages of this thesis. Error refers to the deviation from exact conformity to the truth. It relates to an observed value to the true value by discrepancy; while accuracy means the relationship between a measurement and reality. It refers to the exactness or correctness of a measurement (Jones, 1997). A number of limitations for this thesis range from data collection to data analysis.

3.7.1 Spatial data

Incompleteness of map data: Before starting my field survey, I collected *mauza* maps (the study area consists of 5 *mauzas* with 13 sheets) from the DLRS and the relevant maps from other sources (Table 3.1). All of the *mauza* sheets were not available in the DLRS. In order to get all the sheets for preparing a base map, I made a contact with the local Land Revenue Office, but I did not find even one sheet. Interestingly, the local people had a very old, dirty, and torn sheet. The plot boundary of that sheet was not clear. I photocopied the sheet and corrected it with ground checking and then digitised the sheet for the complete base map.

Scale and shape: Data quality is an important factor for this thesis. Spatial databases in a GIS are most often built from existing analogue maps. Data derived from different sources and in different formats have exhibited many types of error. The availability and quality of spatial data is an important phenomenon for GIS. There is a lack of similarity in scale and shape of *upazila*, *unions* and *mauzas* on different maps produced by the LGED, the BBS, and the SRDI. The dissimilarities of scale and shape of maps were a major problem in digitising map data. Problems arose, for instance, when the Mahmudpur canal is inside the study area or outside the study area or the boundary line is in the middle of the canal. In such case, people's opinion and the *mauza* maps from the DLRS were used. In addition, the shape of the study area is different in maps produced by the LGED and the BBS.

Positional accuracy: Positional accuracy measures the degree of discrepancy between map feature location and database feature location (DeMers, 2002). Positional error stems from inaccuracies in the horizontal placement of point and line data (Worboys, 1997). During the checking and comparison of point and line data from different sources of maps, I found serious inaccuracies in the location of different roads and different points. For instance, the main road (line feature) and the UP Headquarters (a point featrure) on different maps were not placed in the same positions. To overcome these positional inaccuracies, I conducted ground checking of the map data and then stored them in a GIS format.

Delineation of ward boundaries: In the study area, there were no significant boundary lines between wards. There was no problem in identifying the *mauza* boundary since it is mentioned in the DLRS *mauza* maps, but problems arose when I tried to use the ward boundaries. In the study area, there are nine wards. During the field survey, I faced huge problems to delineate the ward boundary. I asked every elected representative about the boundary of their respective wards, but they failed to provide me with the accurate boundary. I then arranged a meeting with the chairman of the Ghona *Union* and members of all the wards, as well as the local leaders in order to discuss the problems of the ward boundary. I found many stories when I was in the field investigation for the boundary information:

(a) In a household, a man is a voter of ward-8 and another person of the same household is for ward-9. When I put this problem to the elected members of wards - 8 and 9, they were astonished and they blamed the government, although they are a part of the local government. This type of story was found between Wards - 1 and 2, wards - 3 and 4, and wards - 6 and 7.

(b) There were no complete boundary lines of wards within the agricultural lands. It is also noted that some scattered settlements within the agricultural lands were found in the study area and problems also arose when some people of these scattered settlements are enlisted to two different wards. Following the opinions of the local people, local leaders, local chairman and members, and local *amin* (local government land record surveyor), I have delineated the complete ward boundary.

(c) A road was found as a boundary line between wards - 7 and 8. But, it was interesting that some households close to that road in ward - 7 were enlisted as the voters of ward - 8. I found this type of problem in wards - 1 and 2, wards - 5 and 6, and wards - 8 and 9. In such cases, I did not modify the map data. I raised these problems at a meeting with the local chairman and members and suggested a change in the voting entitlement of these people to their respective wards.

3.7.2 Attribute database

The availability and quality of attribute data is important for this thesis. The existing necessary attribute information for arsenic issues are associated with data accuracy, lack of data specificity or disaggregated data in relation to time. The required data are sometimes outdated, lacking good quality and are limited mainly to census data. The standardisation, reliability and up-to-dateness and currency of data are important in planning, but these are not available. For instance, I found from a BBS (1997) source that there was a total of 478 tubewells in the study area. But, during my field survey, I found 375 tubewells that were in a good condition; while 19 tubewells were not good, i.e. there were 394 tubewells in January 2001.

How is it possible to execute GIS with such dissimilar spatial data? What sources of data were reliable? What data were appropriate? The base maps, which are essential to GIS, were often lacking or outdated. They were compiled with different accuracies and map scales, making them difficult to integrate into the system and also there was no standardised geo-coding system to link the textual data with the graphic data of the system. What is more, GIS software supporting current and accurate spatial and attribute information were not available for a base map of this thesis. I corrected all of the collected maps and digitised them for the base map.

3.8 CONCLUDING REMARKS

Spatial, quantitative and qualitative data in combination are helpful in analysing arsenic issues in a realistic manner. The spatial and quantitative data for arsenic concentrations in groundwater cover the statistical and spatial needs for mapping arsenic magnitudes in spatial dimensions. The qualitative data about the impact of arsenic on health and social problems cover people's perceptions about their daily life. The qualitative data can be used for demonstrating the real world features of arsenic poisoning of the study area. In addition, the qualitative techniques can disclose the real measure of inherent social and health problems of arsenic-affected people in the study area.

The spatial data for GIS operation were used mainly for spatial analysis of arsenic concentrations and to measure the pattern of risk zones in the study area. With simple GIS methods, I mapped the safe and contaminated tubewells and their actual locations in the study area. The geostatistical interpolation methods in GIS were used to produce point-based isopleth maps to show the spatial arsenic magnitudes in the study area. The IDW, RBF and Ordinary Kriging methods were used in this case.

Quantitative data in the form of attribute information of spatial features were used for statistical analysis for different hypothesis testing. The GLM techniques were mainly used to measure the associations between different arsenic parameters i.e. arsenic concentration with relation to tubewell depth and tubewell installation year.

Qualitative data were used to understand the complexities of human life, i.e. how people understand their worlds and how they create and share meanings about their lives when they are affected with arsenic poisoning. The qualitative methods in this thesis examine the inherent health and social problems of the arsenicosis patients in the study area. The qualitative techniques for both data collection and analytical procedures include PRA techniques, participant observation, in-depth interviews, focus-group discussions, ethnography, hermeneutics, the narrative approach, discourse analysis and grounded theory.

This chapter has mainly focussed on the multi-methods of data collection procedures and data analysis techniques under the framework of field survey and research design. The next few chapters (Chapters IV, V, VI, and VII) will deal with the relevant spatial, statistical and qualitative data analysis outcomes on different arsenic issues following the aims and objectives as well as the research questions.

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CHAPTER IV

SPATIAL ARSENIC MAGNITUDES and EXTENT of EXPOSURE in ENVIRONMENTAL HEALTH RISK

CHAPTER - IV

SPATIAL ARSENIC MAGNITUDES and EXTENT OF EXPOSURE IN ENVIRONMENTAL HEALTH RISK

Analysing the spatial pattern of arsenic magnitudes in groundwater is an important objective of this chapter. In addition, establishing the extent of arsenic exposure to the people will facilitate an understanding of the health effects and population risk estimation over the area. This chapter seeks to explore the spatial distribution and variation of arsenic concentrations in groundwater for analysing and mapping 'problem regions' or 'risk zones' for composite arsenic hazard information by using GIS-based data processing and spatial analysis along with state-of-the-art decision-making techniques. Quantitative data along with spatial information were employed and analysed for this chapter.

The materials presented in this chapter are aimed at providing a spatial and statistical analytical description of the geographical distribution of arsenic magnitudes with the issues of risk assessment in mind. The chapter is divided into seven sections. The first section explores the issue of scale for arsenic data. Section 4.2 describes the spatial pattern of arsenic concentrations by using geostatistical methods and generalised linear models. Section 4.3 presents the analytical output of the arsenic magnitudes with aquifer depth. Section 4.4 discloses the pattern of arsenic concentrations with time. Section 4.5 describes the health effects of arsenic and section 4.6 characterises arsenic risk and identifies spatial risk zones. Finally, section 4.7 makes some concluding remarks on the overall analysis.

4.1 SCALES FOR ARSENIC DATA

4.1.1 Data properties

In analysing the arsenic issues for a micro-level study, it is necessary to recognise the characteristics of the data being mapped. The data for the GIS operation are categorised as: (a) vector spatial data and (b) attribute data. The vector data assigned to the display of points (tubewells, schools etc,); lines (boundary information, roads, rivers etc); and polygons (administrative units, land use, topography etc) are allocated by means of x/y coordinates; while the attribute data are stored as records (rows) of a relational database.

Arsenic concentrations in the groundwater were mainly analysed by collecting water samples from all the tubewells having water availability during January 2001. There were some tubewells in the study area having no water during that period, and the author, in such cases, ignored these tubewells. It is not thought that this will have affected the analysis significantly. In addition, tubewells used for irrigation purposes were not considered for this research since the objective is confined to water used specifically for cooking and drinking purposes. It seems anyway that there are only 19 tubewells for irrigation purposes in the study area. Along with the arsenic content in the water, a number of related attributes (Appendix – F) were collected for each tubewell (Figure 4.1):

(a) Tubewell locations were plotted on the *mauza* maps (scale 1:3960). These locations were transformed into real world co-ordinates in ArcGIS.

(b) The ownership of each tubewell is confined to private individuals, NGO, government and community groups. This attribute can be used in analysing the role of government and NGOs in providing pathogen-free, safe drinking water.

(c) When the tubewell was installed? This information will help us to explore the space-time dimension of arsenic magnitudes.

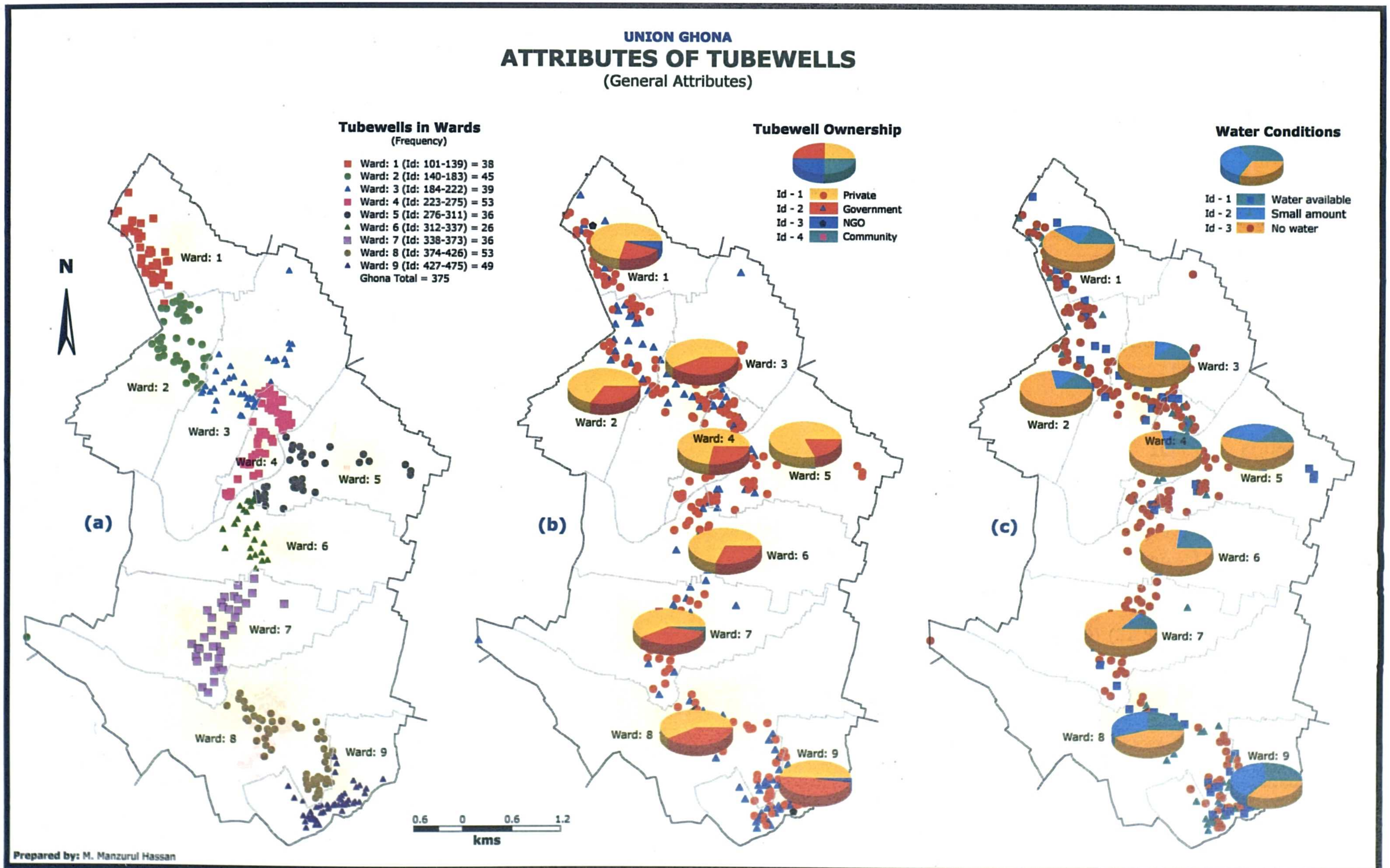

UNION GHONA
ATTRIBUTES OF TUBEWELLS
(General Attributes)
Tubewells in Wards
(Frequency)
Ward: 1 (Id: 101-139) = 38
Ward: 2 (Id: 140-183) = 45
Ward: 3 (Id: 184-222) = 39
Ward: 4 (Id: 223-275) = 53
Ward: 5 (Id: 276-311) = 36
Ward: 6 (Id: 312-337) = 26
Ward: 7 (Id: 338-373) = 36
Ward: 8 (Id: 374-426) = 53
Ward: 9 (Id: 427-475) = 49
Ghona Total = 375
Tubewell Ownership
Id - 1 Private
Id - 2 Government
Id - 3 NGO
Id - 4 Community
Water Conditions
Id - 1 Water available
Id - 2 Small amount
Id - 3 No water
N
(a)
(b)
(c)
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
0.6 0 0.6 1.2
kms
Prepared by: M. Manzurul Hassan

Figure 4.1

(d) The aquifer level of a tubewell will help us to determine which aquifer is safe and which is contaminated with arsenic, or, whether there is any relationship at all between arsenic concentrations and different aquifer levels.

(e) Most of the tubewells in Ghona do not have any water during the summer (February to April) and people have to collect their drinking and cooking water from the few tubewells still having water availability during this season (Figure 4.2). The attribute of tubewell water conditions, i.e. whether the tubewells have any water availability during the spring and summer will measure 'how the local people manage their drinking and cooking water'.

Figure 4.2. Tubewells having no water during the summer (February to April) in the study area.
Source: Field Survey, 2001.

(f) Finally, different attributes of tubewells are of interest in terms of tubewell holder: information on their occupation and income structure was also collected.

4.1.2 Levels of measurement

Levels of measurement depend upon the relationship between the measurements and the attributes. In analysing the spatial magnitudes of arsenic and its spatio-temporal variability, it is important to measure the data level first. Each data level has its own characteristics distinguishable from the other levels and each level can be used for different types of statistical and spatial operations. With arsenic issues, there are many statistics that can be meaningfully applied only to data at a sufficiently strong level of measurement. Measurement theory shows that strong assumptions are required for certain statistics to be meaningful. Measurement theory is here being used to think about the meaning of the arsenic data. It encourages critical assessment of the assumptions behind the analysis.

The main approach for constructing a thematic map on arsenic issues is to interpolate the point data by means of mathematical techniques. Tubewell attributes in terms of arsenic concentrations, tubewell depth, tubewell installation year, etc, can be used for mapping. Measurement of attributes is the process of assigning numbers or symbols in such a way that properties of the numbers or symbols reflect properties of the attribute being measured and a particular way of assigning numbers or symbols to measure is called a scale of measurement (ftp://ftp.sas.com/pub/neural/measurement.html). By 'measurement' is meant two things: (a) the description of what the data represent i.e. a 'naming' function; and (b) the calculation of their quantity i.e. a 'counting' function (O'Brien, 1992).

Before analysing and mapping the database, it is necessary to discuss the measurement levels of the collected arsenic and the relevant database. The database for the arsenic issues is mainly categorised in nominal, ordinal, interval and ratio levels. In Stevens's hierarchy, the nominal and ordinal scales are classed into the categorical or qualitative scales of measurement; while the interval and ratio scales belong to the continuous or quantitative scale of measurement (Stevens, 1959).

In a categorical scale of measurement, the nominal is the simplest scale recognised in Stevens's hierarchy (Stevens, 1959). It serves to identify or distinguish one entity from another (Longley *et al*, 2001). In the nominal scale, numbers or symbols are mainly used to identify an object (Ebdon, 1985). In this research, numerical symbols (for example 101-475) were used to denote the identification of 375 tubewells on the nominal scale of measurement. The nominal map is a mosaic of different coloured points in which the colours are used simply to distinguish the various classes or categories.

The measurement on an ordinal scale involves putting individuals into an order, and ranking them according to different criteria (Ebdon, 1985). The ordinal scale allows the sets to be placed into some form of rank order (O'Brien, 1992). At the ordinal scale of measurement, numbers or symbols are used to identify objects in describing their relationship to other objects (Cliff and Haggett, 1992). The classification of tubewells into shallow tubewells (STW) and deep tubewells (DTW) is an example of ordinal scaling in the definition of tubewell at depths of <150 and >150 metres. The ordinal scale can tell us which tubewells are known to be STW and which are DTW.

The interval scale belongs to the continuous scale of measurement in Stevens's hierarchy (Stevens, 1959). Interval measures are characterised by their ability to class data items into sets (the equivalence property), place them in some form of rank order (the magnitude property), and describe the precise distances (the intervals) between them (O'Brien, 1992). The arsenic concentrations in different tubewells tell us by how much one tubewell has lesser or greater concentrations of arsenic than another.

The isopleth map technique can be used in interpolating isolines for spatial arsenic magnitudes by using the interval scale. The ratio scale in Stevens's hierarchy is the most sophisticated (Stevens, 1959). Measurements made on a ratio scale have all the characteristics of interval scales with the added feature that the ratio of any two values on a ratio scale is independent of the unit of measurement (Ebdon, 1985 and O'Brien, 1992). Arsenic concentrations in tubewells can make sense when a particular tubewell with 0.5 mg/l of arsenic is said to have water that is twice as toxic as another tubewell having 0.25 mg/l of arsenic.

4.2 SPATIAL ARSENIC MAGNITUDES

Which tubewells are safe and which are contaminated? Or, which areas are safe and which areas are contaminated? In a quest for the answer to these questions, data from the collected tubewell samples ($n = 375$) were analysed by spatial interpolation. The spatial pattern of arsenic concentrations in the study area is highly uneven: some tubewells are highly contaminated with arsenic and some are less so; some areas are high with arsenic and some areas are low (Figure 4.3). Arsenic concentrations in the study area range between <0.003 mg/l and 0.600 mg/l. The mean arsenic concentration of the 375 tubewells in the study is 0.238 mg/l and the standard deviation is 0.117 mg/l.

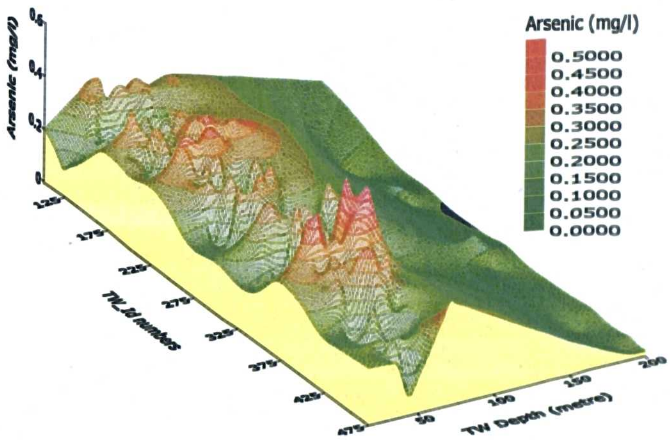


Figure 4.3: Three dimensional view of arsenic concentrations in the study area.

Arsenic concentrations in groundwater can be classified into different categories based on arsenic magnitudes and statistical procedures, but here, the author classified the concentrations of arsenic into different classes based on different permissible limits (Table 4.1 and Figure 4.4): (a) the WHO permissible level (<0.01 mg/l); (b) the Bangladesh standard maximum contaminant level - MCL (0.01-0.05 mg/l); (c) the moderate contamination level (0.05-0.1 mg/l); (d) the high contamination level (0.1-0.3 mg/l); and (e) the severe contamination level (>0.3 mg/l). This figure can be framed into two different broad categories on the

Table 4.1.
Geographical distribution of arsenic concentrations in ground water of different administrative wards (WDs).

Major Groups	Arsenic magnitudes (mg/l)	Detailed Classification	Number of TWs in different Wards									
			WD-1	WD-2	WD-3	WD-4	WD-5	WD-6	WD-7	WD-8	WD-9	Total
Safe Level	<0.01	WHO limit	-	-	1 (0.27)	-	-	1 (0.27)	-	-	2 (0.53)	4 (1.07)
	0.01-0.05	Bangladesh standard limit	-	2 (0.53)	-	3 (0.80)	1 (0.27)	3 (0.80)	-	1 (0.27)	3 (0.80)	13 (3.47)
Contamination Level	0.05-0.1	Moderate contamination	2 (0.53)	2 (0.53)	1 (0.27)	4 (1.07)	-	6 (1.60)	8 (2.13)	2 (0.53)	7 (1.87)	32 (8.53)
	0.1-0.3	High contamination	23 (6.13)	22 (5.87)	12 (3.20)	28 (7.47)	27 (7.20)	12 (3.20)	14 (3.73)	27 (7.20)	35 (9.33)	200 (53.33)
	>0.3	Severe contamination	13 (3.47)	19 (5.07)	25 (6.67)	18 (4.80)	08 (2.13)	4 (1.07)	14 (3.73)	23 (6.13)	2 (0.53)	126 (33.60)
		Ghona Total	38 (10.13)	45 (12.00)	39 (10.40)	53 (14.13)	36 (9.60)	26 (6.93)	36 (9.60)	53 (14.13)	49 (13.07)	375 (100%)

Data Source: Field Survey, 2001.
Figures in parentheses indicate the net percent of the sample TWs.
(The dataset is classified on the basis of different permissible limits of daily arsenic ingestion).

basis of the official Bangladesh standard daily maximum tolerable limit of 0.05 mg/l. These are: (a) a safe level (<0.05 mg/l of arsenic); and (b) a contamination level (>0.05 mg/l of arsenic). Through this classification process, we can identify the safe and contaminated tubewells. Figure 4.4 shows the safe and contaminated tubewells in different administrative wards of the study area. Moreover, the detailed classification of arsenic concentrations (Figure 4.5) shows at a glance the situation of the different tubewells in the study area.

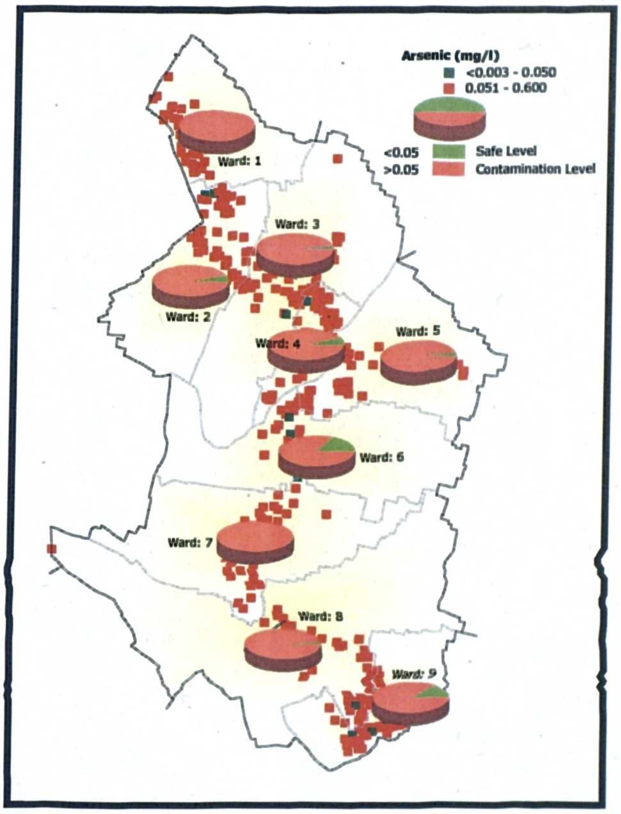


Figure 4.4: Safe and contaminated tubewells in the study area.

Spatial interpolation methods: Thematic maps were developed to define the pattern of arsenic magnitudes and its spatial variation by using spatial interpolation methods. The primary purpose of the isoline map in the thematic mapping concept is to provide a basis for estimating total arsenic concentrations of the tubewells. Spatial interpolation is a significant operation in GIS. The spatial pattern of arsenic magnitudes was analysed and interpolated in a GIS

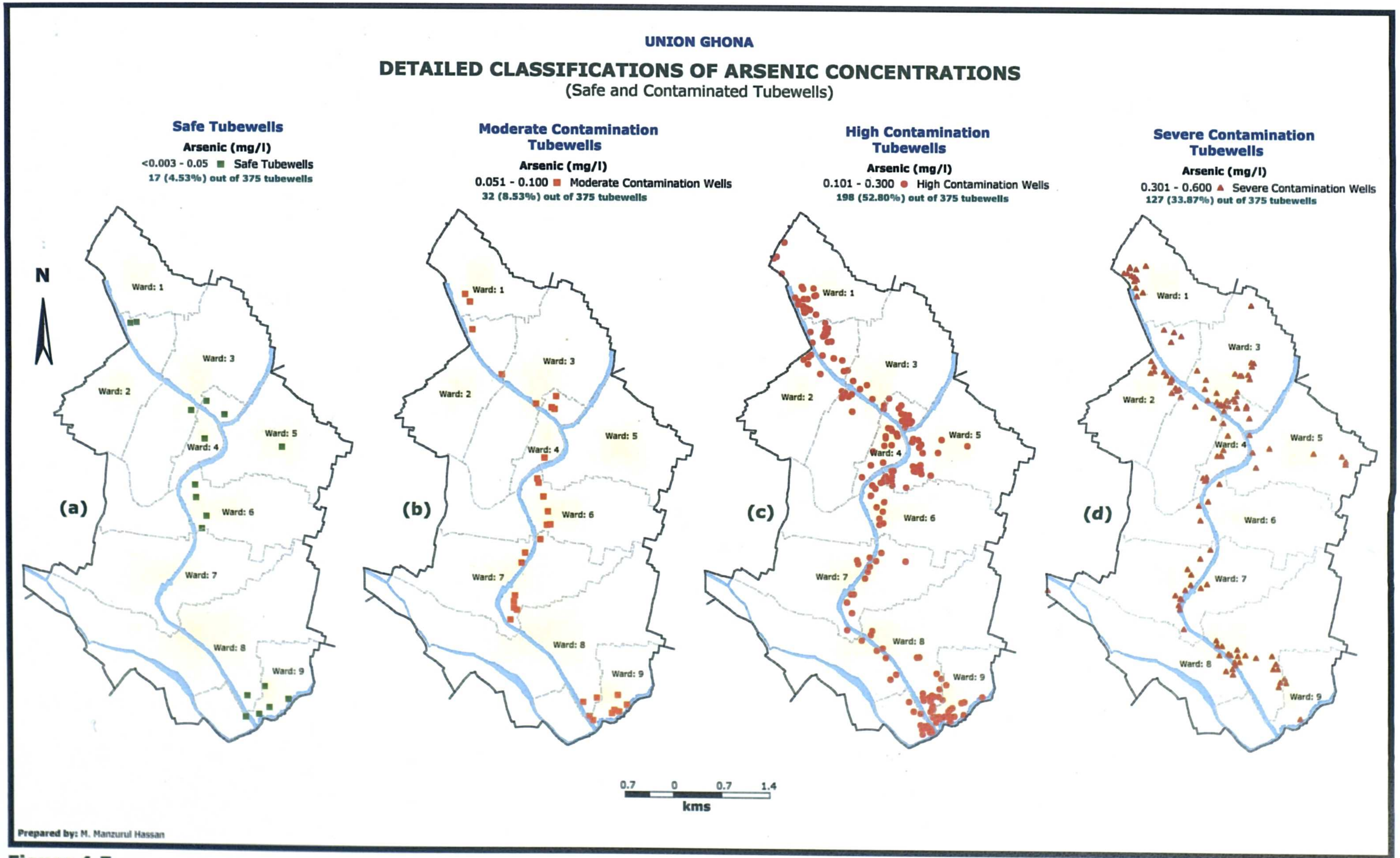

UNION GHONA
DETAILED CLASSIFICATIONS OF ARSENIC CONCENTRATIONS
(Safe and Contaminated Tubewells)
Safe Tubewells
Arsenic (mg/l)
<0.003 - 0.05 Safe Tubewells
17 (4.53%) out of 375 tubewells
Moderate Contamination Tubewells
Arsenic (mg/l)
0.051 - 0.100 Moderate Contamination Wells
32 (8.53%) out of 375 tubewells
High Contamination Tubewells
Arsenic (mg/l)
0.101 - 0.300 High Contamination Wells
198 (52.80%) out of 375 tubewells
Severe Contamination Tubewells
Arsenic (mg/l)
0.301 - 0.600 Severe Contamination Wells
127 (33.87%) out of 375 tubewells
N
(a)
(b)
(c)
(d)
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
0.7 0 0.7 1.4
kms
Prepared by: M. Manzurul Hassan

Figure 4.5

environment (ArcGIS - version 8.1) by using the IDW, RBF and Kriging methods because of their exact interpolation capability by comparison with other interpolation techniques (details in chapter III). The prediction maps produced by the IDW, RBF and Kriging interpolation methods for arsenic magnitudes reveal the spatial arsenic concentration pattern.

The arsenic interpolation maps produced by the IDW method are based on the weighting of a random function for the tubewells, while in the RBF method, the surface passes through all the measured data values, picking up local variation. The thin-plate spline technique of the RBF method was used for smoothing. The IDW prediction map was produced with the optimised power value of 1.5911 having 40 neighbours and an ellipse neighbourhood shape along with 3 sector modes. Like the IDW method, the RBF prediction map was prepared with the same parameters except it has the optimised power value of 2.

The kriging map based on an ordinary kriging (OK) model is constrained by the spherical semivariogram fits. The experimental variogram was computed from the raw data and a mathematical model was fitted to the arsenic concentration values by weighted least-squares approximation, using ArcGIS. The parameters of the variogram model for arsenic concentrations were used with their values for estimating their concentrations over the area by kriging.

The study area experiences a continuous variation in arsenic magnitudes over space. The experimental variogram of the arsenic concentrations suggests that the variation is spatial and it was fitted best by a spherical model. A graph of the semivariogram for the arsenic data shows $\gamma(h)$ as a function of lag distance h and the model illustrates the features common to the arsenic semivariogram (Gerlach *et al*, 2001): (a) $\gamma(h)$ increases from smaller to larger lags but a limiting 'sill' is always found; (b) $\gamma(h)$ approaches for small lags suggesting the large 'nugget effect'; and (c) the spherical semivariogram model gives good and acceptable fits to $\gamma(h)$.

4.2.1 Which areas and which tubewells are safe?

Areas having concentrations of arsenic below 0.05 mg/l (Bangladesh standard permissible limit) of arsenic are classed into the safe category. From the prediction map of the IDW interpolation method, it has been identified that lower arsenic concentrations are located mainly in the central zone of the study area (Figure 4.6a). Moreover, arsenic concentrations with lower magnitudes are recognised in some part of northern and southern zones of the study area (Figure 4.6a). The middle part has the largest portion of the safe zones, especially in Ward-6 (Figure 4.6a). It has been measured from the IDW prediction map that the safe zones cover a very small portion (81.00 hectare) of the study area, about 4.69% of the total land (Table 4.2).

Table 4.2.

Spatial arsenic concentrations with different interpolation methods.

Major groups	Arsenic magnitudes (mg/l)	Detailed Classifications	IDW method	RBF method	Ordinary Kriging method
Safe Level	<0.05	Safe (DoE standard)	81 (4.69)	32.2 (1.90)	51.3 (2.97)
Contamination Level	0.05 - 0.1	Moderate	363 (21.0)	122.8 (7.1)	173 (10.03)
	0.1 - 0.3	High	467 (27)	414 (24.0)	587 (34.0)
	>0.3	Severe	815 (47.31)	1157 (67.0)	915 (53.0)

Data Source: Field survey, 2001.
(Area under each category has been calculated by ArcGIS)
Figures in the parentheses indicate the percent of respective land area (hectare).

The RBF prediction map (Figure 4.6b) reveals the scatter of zones of a low level of contamination of arsenic from north to south of the study area. The safe areas are mainly located in the central and southern part in Wards – 5, 6, 7 and 9. In the RBF prediction map, the safe zones (32.80 hectare) in the study area cover about 1.90% of the total area.

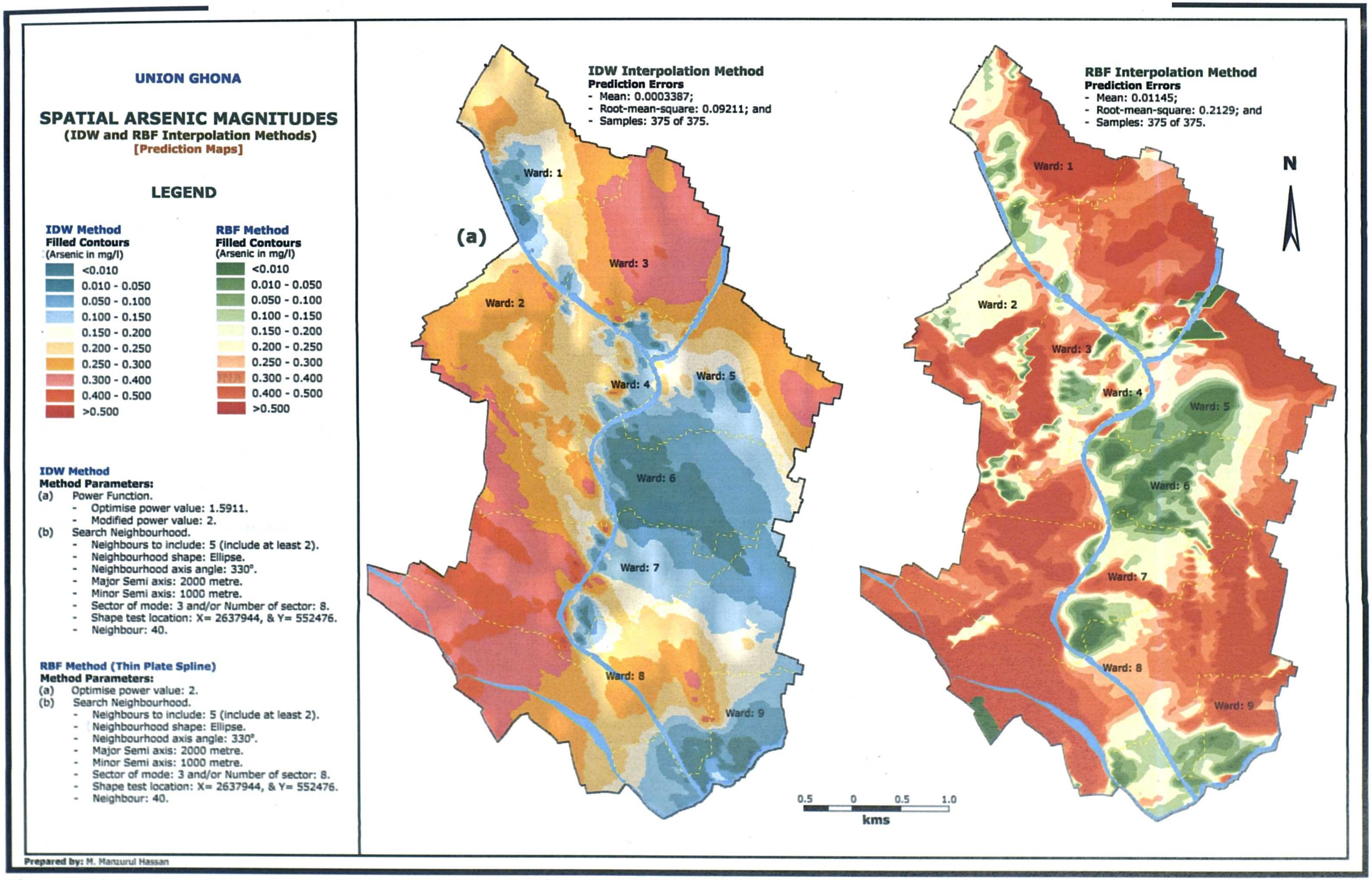

UNION GHONA
SPATIAL ARSENIC MAGNITUDES
(IDW and RBF Interpolation Methods)
[Prediction Maps]
LEGEND
IDW Method
Filled Contours
(Arsenic in mg/l)
<0.010
0.010 - 0.050
0.050 - 0.100
0.100 - 0.150
0.150 - 0.200
0.200 - 0.250
0.250 - 0.300
0.300 - 0.400
0.400 - 0.500
>0.500
RBF Method
Filled Contours
(Arsenic in mg/l)
<0.010
0.010 - 0.050
0.050 - 0.100
0.100 - 0.150
0.150 - 0.200
0.200 - 0.250
0.250 - 0.300
0.300 - 0.400
0.400 - 0.500
>0.500
IDW Method
Method Parameters:
(a) Power Function.
- Optimise power value: 1.5911.
- Modified power value: 2.
(b) Search Neighbourhood.
- Neighbours to include: 5 (include at least 2).
- Neighbourhood shape: Ellipse.
- Neighbourhood axis angle: 330°.
- Major Semi axis: 2000 metre.
- Minor Semi axis: 1000 metre.
- Sector of mode: 3 and/or Number of sector: 8.
- Shape test location: X= 2637944, & Y= 552476.
- Neighbour: 40.
RBF Method (Thin Plate Spline)
Method Parameters:
(a) Optimise power value: 2.
(b) Search Neighbourhood.
- Neighbours to include: 5 (include at least 2).
- Neighbourhood shape: Ellipse.
- Neighbourhood axis angle: 330°.
- Major Semi axis: 2000 metre.
- Minor Semi axis: 1000 metre.
- Sector of mode: 3 and/or Number of sector: 8.
- Shape test location: X= 2637944, & Y= 552476.
- Neighbour: 40.
(a)
IDW Interpolation Method
Prediction Errors
- Mean: 0.0003387;
- Root-mean-square: 0.09211; and
- Samples: 375 of 375.
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
RBF Interpolation Method
Prediction Errors
- Mean: 0.01145;
- Root-mean-square: 0.2129; and
- Samples: 375 of 375.
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
N
0.5 0 0.5 1.0
kms
Prepared by: M. Manzurul Hassan

Figure 4.6

The kriged prediction shows the isoline maps of estimated arsenic magnitudes and again the problem is in the west and northeast (Figure 4.7). The safe areas identified in the kriged estimation are especially in Ward – 5 and this time the safe zones cover about 2.97% (51.30 hectare) of the total study area (Figure 4.7). Like the IDW interpolation method, it has been found from the Ordinary Kriging estimation map that the safe zones are mainly recognised on the areas having concentrations of arsenic <0.05 mg/l (Figure 4.7).

It has been found from the study area that only 4.50% of the tubewells (17 out of 375) belong to this safe level. The arsenic concentration present in this broad band ranges between <0.003 mg/l in Ward-9 and 0.043 mg/l in Ward-2 and the mean ($\overline{X}$) arsenic magnitude lies at 0.022 mg/l; while the standard deviation (δ_n) is 0.012 mg/l (Table 4.3).

Table 4.3.
Statistical properties of the arsenic data from 375 tubewells in the study area.

Descriptive Statistics	Overall	Safe level	Contamination level
Frequency	375 (100%)	17 (4.53%)	358 (95.47%)
X-minimum	<0.003 mg/l	<0.003 mg/l	0.057 mg/l
X-maximum	0.6 mg/l	0.043 mg/l	0.6 mg/l
Mean	0.238 mg/l	0.022 mg/l	0.248 mg/l
Variance	0.014 mg/l	0.000144 mg/l	0.011881 mg/l
Std. Deviation	0.117 mg/l	0.012 mg/l	0.109 mg/l

Data Source: Field Survey, 2001.
Figures in the parentheses indicate the net percent of the sample tubewells.
(The arsenic data are calculated by descriptive statistical procedures).

In the safe band, 4 tubewells (1.07%) meet the WHO and USEPA standard level (<0.01 mg/l) and 13 tubewells (3.47%) qualify at the Bangladesh Standard Permissible Limit (<0.05 mg/l). There is no safe tubewell in Ward-1 or Ward-7 (Table 4.1 and Figure 4.4). From the field survey, it has also been found that the arsenic-free tubewells in the safe band occur in the south, middle and northern part of the study area along the British *Khal* (Canal), within the Ganges alluvial plain (Figure 4.5).

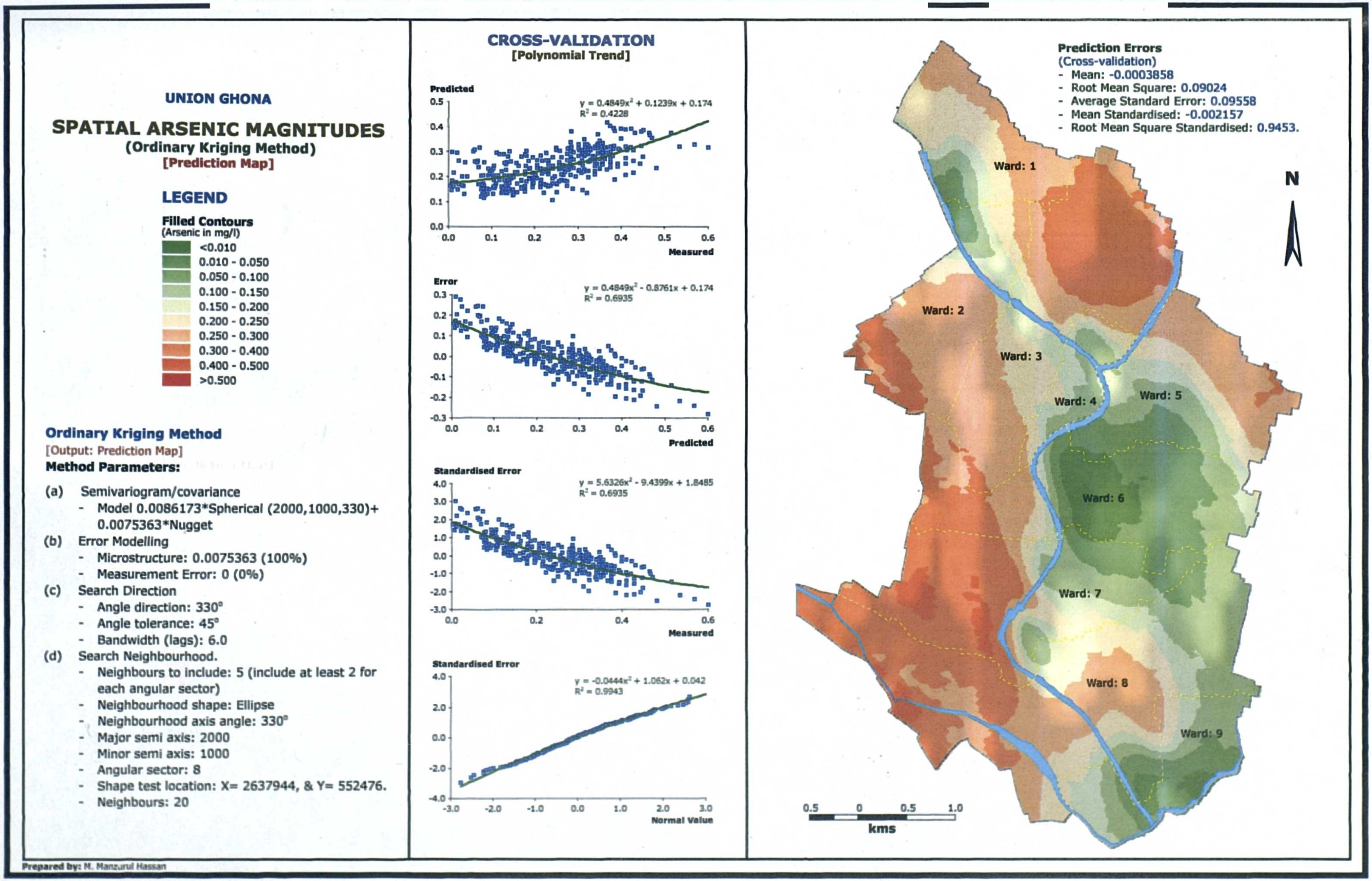

UNION GHONA
SPATIAL ARSENIC MAGNITUDES
(Ordinary Kriging Method)
[Prediction Map]
LEGEND
Filled Contours
(Arsenic in mg/l)
<0.010
0.010 - 0.050
0.050 - 0.100
0.100 - 0.150
0.150 - 0.200
0.200 - 0.250
0.250 - 0.300
0.300 - 0.400
0.400 - 0.500
>0.500
Ordinary Kriging Method
[Output: Prediction Map]
Method Parameters:
(a) Semivariogram/covariance
- Model 0.0086173*Spherical (2000,1000,330)+ 0.0075363*Nugget
(b) Error Modelling
- Microstructure: 0.0075363 (100%)
- Measurement Error: 0 (0%)
(c) Search Direction
- Angle direction: 330°
- Angle tolerance: 45°
- Bandwidth (lags): 6.0
(d) Search Neighbourhood.
- Neighbours to include: 5 (include at least 2 for each angular sector)
- Neighbourhood shape: Ellipse
- Neighbourhood axis angle: 330°
- Major semi axis: 2000
- Minor semi axis: 1000
- Angular sector: 8
- Shape test location: X= 2637944, & Y= 552476.
- Neighbours: 20
CROSS-VALIDATION
[Polynomial Trend]
Predicted
Measured
y = 0.4849x² + 0.1239x + 0.174
R² = 0.4228
Error
Predicted
y = 0.4849x² - 0.8761x + 0.174
R² = 0.6935
Standardised Error
Measured
y = 5.6326x² - 9.4399x + 1.8485
R² = 0.6935
Standardised Error
Normal Value
y = -0.0444x² + 1.062x + 0.042
R² = 0.9943
Prediction Errors
(Cross-validation)
- Mean: -0.0003858
- Root Mean Square: 0.09024
- Average Standard Error: 0.09558
- Mean Standardised: -0.002157
- Root Mean Square Standardised: 0.9453.
N
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
0.5 0 0.5 1.0
kms
Prepared by: M. Manzurul Hassan

Figure 4.7

4.2.2 Which areas and which tubewells are contaminated?

Areas having concentrations of arsenic above the Bangladesh standard daily maximum tolerable limit of 0.05 mg/l are confined to the contaminated category. It has been identified from the IDW prediction map that higher arsenic concentration zones are located on the western side of the British *Khal* and the northeast part except the north-western, eastern, middle and southern part of the study area (Figures 4.6a). The map shows the severe arsenic contamination zones in the north-eastern part in Ward-3 along with the western part of Wards-7 and 8; while the moderate contamination zones are located on the western side of Ward-2, the southern part of Ward-3 and in the middle part of Ward-8 (Figure 4.6a). The IDW map shows that the severe contaminated zones cover a significant portion of total land (47.31% i.e. 815 hectare) of the study area; while the moderate contaminated zones and the high contaminated zones cover about 21% (363 hectare) and 27% (467 hectare) of the total land respectively (Table 4.2).

With the RBF prediction map, the study area has been classified with different contamination levels of arsenic (Figure 4.6b). The map shows different levels of contamination zones in the western, eastern and north-eastern part of the study area. The contaminated zones cover maximum areas of Wards-1, 3, 7 and 8. In the RBF prediction map, the severe contamination zones cover about 67% (1157 hectares) of the total area; while the moderate and high contamination zones in combination cover about 31.1% (537 hectare) land of the study area (Table 4.2).

The kriged estimation map shows the increasing pattern of arsenic concentrations from east to west, especially from the west bank of the British *Khal* (Figure 4.7). In addition, the northeast parts of the study area are found to be contaminated. Along with the northern part of Ward-3, the contaminated zones cover the western part of Wards-2, 3, 6, 7 and 8. It has been measured from the kriging estimation map that the high and severe contamination zones cover about 87% (1502 hectare) of the land of the study area; while the moderate contamination zones cover about 10.03% (173 hectare) of the land of the study area (Table 4.2).

It has been calculated from the field database that about 95.50% (358) of the tubewells are contaminated with arsenic. The present arsenic concentrations in the contamination category range from 0.057 mg/l in Ward-3 to 0.6 mg/l in Ward–7 and the mean ($\overline{X}$) arsenic magnitude is 0.248 mg/l; while the standard deviation (δ_n) in this broad category is on 0.109 mg/l (Tables 4.1 and 4.3). It is noteworthy that the mean arsenic concentration in this category is 5 times higher than the Bangladesh standard limit and 25 times higher than the WHO permissible limit.

In the contamination band, only 32 tubewells (8.53%) belong to the range of moderate contamination level (0.05 - 0.1 mg/l); 200 tubewells (53.33%) are at the high contamination (0.1 - 0.3 mg/l) level; while the remaining 126 tubewells (33.60%) are in the severe contamination (>0.3 mg/l) band (Table 4.1). I found from the database that the arsenic-contaminated tubewells under the moderate contamination category occur mainly in the south (Wards-8 and 9) as a cluster; the high arsenic levels are found in the northern, middle and southern portion of the study area; while all the tubewells in severe contamination category occur from north to south along the British *Khal* within the zone of the Ganges alluvial plain (Figure 4.5). All the tubewells in Ward-1 and Ward-7 are contaminated with arsenic (Table 4.1).

Arsenic concentration in groundwater is highly uneven over space. The pattern of arsenic magnitudes varies considerably and unpredictably over distances of a few metres, which results in the large nugget variances (0.008762) of the spherical variogram (Figure 4.8). In the study area, about 46% of tubewells are located within 25 metres of each other (Figure 4.9). This distance zone of nearest tubewells and arsenic concentration of each tubewell in combination reveals the highly uneven spatial variation of arsenic concentrations in the groundwater.

The overall pattern of arsenic magnitudes shows a broad band with low contamination running along the right bank of the British *Khal* and the areas near the Ghona UP Headquarters. It has been found from the prediction maps (Figures 4.6 and 4.7) that the safe zones are mainly concentrated in the north, central and south part of the study area in a scattered manner; while the contaminated zones are concentrated into the west, northeast and east sides. The south and southwest regions appear to show safe zones with some local variability.

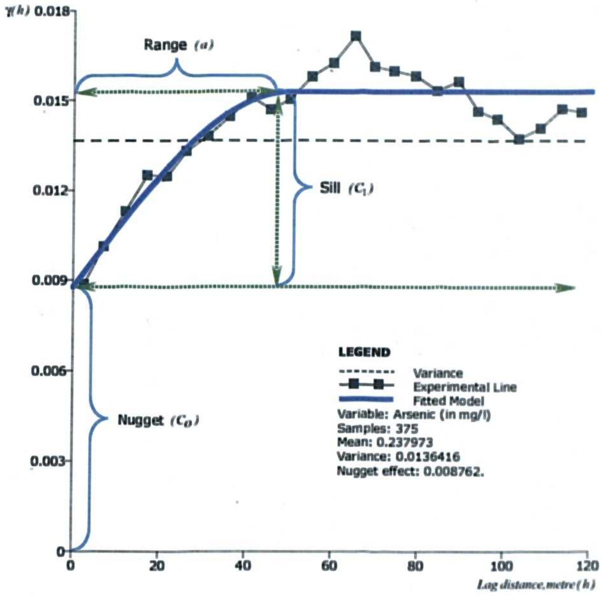


Figure 4.8: Spherical semivariogram for arsenic concentrations.

The contamination zones are found everywhere in the study area but with a decrease in the degree of contamination from west to east. The central part of the study area is low contaminated – in an area roughly corresponding to the Ganges alluvial floodplain. The west and northeast of the study area are generally more contaminated; while the southwest part of the study area is contaminated in a highly irregular pattern (Figures 4.6 and 4.7).

The pattern of variation is particularly distinctive because the arsenic concentrations appear to have an inverse relation with relief. From the IDW and RBF maps (Figure 4.6) and the kriged prediction map (Figure 4.7) we can see that arsenic concentrations decrease from west to east: they are largest in the low-lying area of the West and north-east and smallest along the right side on the British *Khal* of the study area. The safe zones are associated with the highest elevations which are in the north, central and southern part of the area, and the contamination zones are on the west and northeast part where the elevation is low and agriculture predominant.

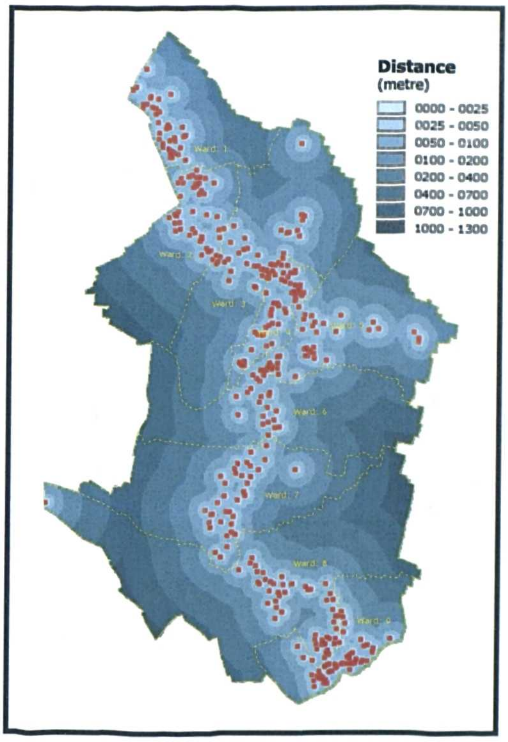


Figure 4.9: Distance zones to the nearest tubewell.

The literature concerning arsenic magnitudes shows that the pattern of arsenic magnitudes is usually described using concentrations of arsenic in individual tubewells rather than by the interpolation of values and production of isoline maps for the distribution pattern of arsenic magnitudes. Isoline mapping for this study gives a picture of arsenic concentrations with spatial characteristics. Isoline mapping with geostatistical approaches pointed out those zones with safe and low to high concentrations of arsenic. Since the interpolation methods adopted for this study have advantages over the simple point distribution technique, this study therefore calls for a new approach.

4.3 ARSENIC MAGNITUDES WITH DEPTH

Do arsenic concentrations differ with the variation of aquifer levels or not? Or, which aquifer is safe and which aquifer is contaminated? Is the deep aquifer safe? In a quest for the answer to these questions, the collected tubewell samples were mainly analysed by statistical methods, especially the generalised linear models (GLMs) because of their advantageous position vis-a-vis normal linear regression. GLMs are used to do regression modelling for non-normal data, using methods closely analogous to normal linear methods for normal data (McCullagh and Nelder, 1989). The GLMs are a development of linear models to accommodate both non-normal response distributions and transformations to linearity (www.isds.duke.edu/computing/S/Snotes/node81.html) in a clean and straightforward way. Since the arsenic data are not normally distributed, GLMs are suitable for this research.

4.3.1 What level of arsenic exists in different aquifers?

This section points out the geographical distribution of arsenic magnitudes with aquifer levels. In the study area, the aquifer depth ranges from 18 metres to 200 metres. Drawing upon the sub-surface aquifer (≤50 metre), upper-shallow aquifer (51-75 metre) and lower-shallow aquifer (76-150 metre), 153 (40.80%), 172 (45.87%) and 38 (10.13%) tubewells have been identified respectively; while at the deep aquifer (>150 metre), only 12 (3.20%) tubewells have been found (Table 4.4).

Arsenic concentrations in the study area are highly uneven with aquifer levels. It is calculated from the database that there is an increasing pattern of arsenic concentrations with depth down to at least 75 metres, with some regional variations (Figure 4.10) and a very little contamination was found in tubewells at the deepest aquifer (>150 metres), with concentrations of arsenic of ≤0.05 mg/l (Table 4.5).

The field data show that at a depth of ≤50 metres, only 1.07% of the total tubewells (4 out of 375) are found to be safe and 40.80% (153 out of 375) are

Table 4.4.
Ward-wise geographical distribution of tubewells with aquifer levels.

Major Aquifer Levels	Depth (metre)	Detailed Classification	Tube wells in different Wards										Safe Level	Cont. Level
			WD-1	WD-2	WD-3	WD-4	WD-5	WD-6	WD-7	WD-8	WD-9	Total		
Shallow aquifer (<150 metres)	≤50	Sub-surface aquifer	11 (2.93)	20 (5.33)	19 (5.07)	16 (4.27)	5 (1.33)	9 (2.40)	17 (4.53)	19 (5.07)	37 (9.87)	**153** (40.80)	4 (1.07)	149 (39.73)
	51-75	Upper shallow aquifer	23 (6.13)	21 (5.60)	14 (3.73)	30 (8.00)	19 (5.07)	12 (3.20)	14 (3.73)	32 (8.53)	7 (1.87)	**172** (45.87)	2 (0.53)	170 (45.33)
	76-150	Lower Shallow aquifer	4 (1.07)	4 (1.07)	5 (1.33)	4 (1.07)	11 (2.93)	3 (0.80)	5 (1.33)	1 (0.27)	1 (0.27)	**38** (10.13)	1 (0.27)	37 (9.87)
Deep aquifer (>150 metres)	>150	Deep aquifer	-	-	1 (0.27)	3 (0.80)	1 (0.27)	2 (0.53)	-	1 (0.27)	4 (1.07)	**12** (3.20)	10 (2.67)	2 (0.53)
		GHONA Total	**38** (10.13)	**45** (12.00)	**39** (10.40)	**53** (14.13)	**36** (9.60)	**26** (6.93)	**36** (9.60)	**53** (14.13)	**49** (13.07)	**375** (100)	**17** (4.53)	**358** (95.47)

Data Source: Field Survey, 2001.
(The dataset is classified on the basis of different aquifer levels and the figures in the parentheses indicate the net percent of the sample TWs).
[The arsenic concentration in TWs is less than 0.05 mg/l is recognised as the **safe level**; while the value for 0.05 mg/l and more is known as the **contamination level**].

contaminated with arsenic at different concentration levels; at the 51-75 metre aquifer, 0.53% of tubewells (2 out of 375) are found to be safe and 45.33% (170 out of 375) are contaminated; while at the 76-150 metre aquifer level, only 0.27% of tubewells (1 out of 375) are safe and 9.60% (36 out of 375) are contaminated (Table 4.5). The mean arsenic concentrations in the sub-surface aquifer, upper-shallow aquifer, lower-shallow aquifer, and deep aquifer are 0.227 mg/l, 0.257 mg/l, 0.255 mg/l, and 0.025 mg/l respectively, which indicate the variation of arsenic concentrations over aquifer depths (Table 4.5).

There is a marked relationship between the aquifer depths and the pattern of arsenic concentrations in the study area. From the GLMs it is calculated that, at the 95% confidence level with a standard error of 0.0336995, there is a low negative correlation ($r = -0.0999765$) between aquifer levels and arsenic concentrations in the study area. The inverse relation between aquifer depth and arsenic concentrations is striking visually, yet the correlation coefficient between the values indicates only a weak relationship (Figure 4.10).

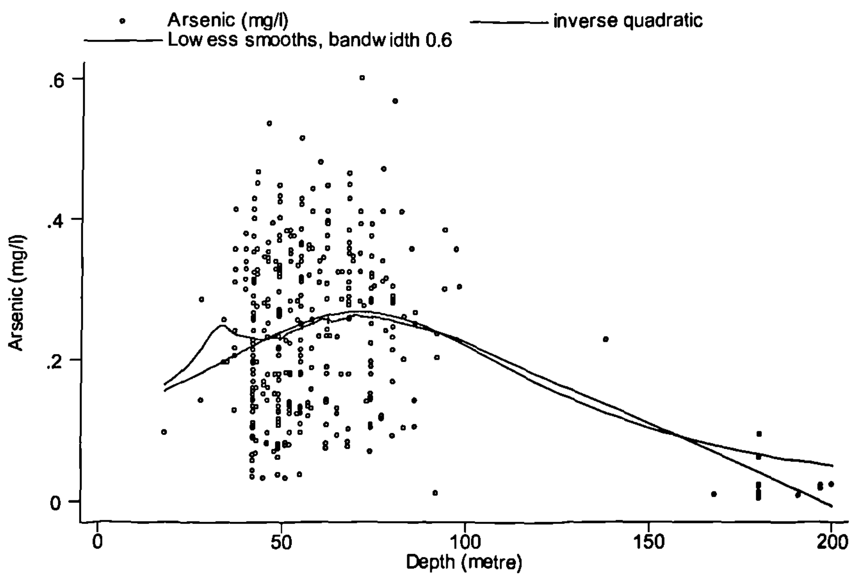


Figure 4.10: Generalised Linear Models between arsenic and depth relationships.

Various reports and published articles show that arsenic concentrations decrease with the increase of aquifer depth, and specifically at the deep aquifer the

Table 4.5.
Geographical distribution of arsenic with aquifer levels
and descriptive statistics.

Depth (metre)	Arsenic magnitudes					Overall picture					
	Safe Level		Contamination Level			Safe Level		Cont. Level		Total	
	<0.01	0.01-0.05	0.05-0.1	0.10-0.3	>0.3	F	Statistics	F	Statistics	F	Statistics
≤50	-	4 (1.07)	17 (4.53)	86 (22.93)	46 (12.27)	4 (1.07)		149 (39.73)	**0.2325** *+0.0142*	153 (40.80)	**0.227** *+0.0078*
51-75	-	2 (0.53)	12 (3.20)	90 (24.00)	68 (18.13)	2 (0.53)	**0.0321** *-0.9149*	170 (45.33)	**0.259** *+0.072*	172 (45.87)	**0.257** *+0.0962*
76-150	-	1 (0.27)	1 (0.27)	23 (6.13)	13 (3.47)	1 (0.27)		37 (9.87)	**0.271** -0.051	38 (10.13)	**0.264** -0.035
>150	4 (1.07)	6 (1.60)	2 (0.53)	-	-	10 (2.67)	**0.0144** *+0.4892*	2 (0.53)	-	12 (3.20)	**0.025** *-0.0789*
GHONA Total:	4 (1.07)	13 (3.47)	32 (8.53)	199 (53.07)	127 (33.87)	17 (4.53)	**0.0217** *-0.767*	358 (95.47)	**0.248** *+0.0433*	375 (100.00)	**0.238** *-0.2157*

Data Source: Field Survey, 2001.
Figures in the parentheses indicate the net percent of the sample tubewells. The **bold** figures represent the average arsenic concentration of tubewells at the respective depths; while the *italic* figures are for correlation co-efficient values between arsenic concentrations and depths of tubewells.

At the safe level, in the depth of <50m, the **mean** arsenic is 0.0363 mg/l and the **r**-value is –0.304 for 4 samples; while at the depth of <150m, the **mean** arsenic concentration is 0.0321 and the **r**-value is -0.9149 for 7 samples. At the contamination level, in the depth between 51-150m, the **mean** value of arsenic concentration is 0.261 and the **r**-value is +0.057.

presence of arsenic concentrations is low. An increase in arsenic concentration with depth down to at least 70 metres has been found by Nickson (1997). In contrast, the Asian Arsenic Network (AAN) in their research shows a decrease in arsenic with aquifer depth (Tsushima, 1997). The NRECA (1997) has reported highly contaminated wells (>0.25 mg/l) occurring within a depth range of 20-40 metres below ground; while only a few samples (>0.1 mg/l) occur below 100 metres depth. The BGS report (BGS, 1999) notes that only 1% of deep tubewells are contaminated with arsenic above 0.05 mg/l; while 41% of the contaminated tubewells are tapping water from shallow aquifers.

The correlation value ($r = -0.0999765$) shows that arsenic concentrations decrease slowly with the increase of aquifer depth. The inverse quadratic trend line shows an increasing trend of arsenic concentrations up to a depth of 75 metres and a decreasing trend beyond that; while the lowess trend line shows more or less the same with inverse quadratic trend with little fluctuation (Figure 4.10). The spherical semivariogram model also shows the relationships between the pattern of arsenic concentrations and aquifer depths. The large nugget variance (0.00688) represents the considerable locally erratic component of the variation of arsenic with depth (Figure 4.11). The computed semivariogram for arsenic and depth shows evidence of a trend and also the values change in a fairly continuous way.

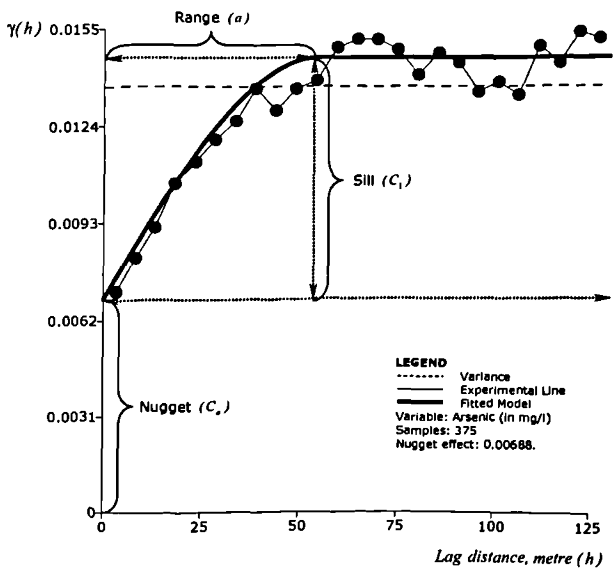


Figure 4.11: Spherical semivariogram for arsenic with depth.

The scatter diagrams of arsenic concentrations with a polynomial regression line against different aquifer depths and the correlation coefficient values show different types of relationships (Figure 4.12). The correlation coefficient value ($r = +0.0078$) for the sub-surface aquifer indicates a very low positive relationship with arsenic and there is a tendency to increase the concentrations with the increase of depth (Figure 4.12). The value ($r = +0.096$) for the upper-shallow aquifer indicates a low positive relationship between arsenic concentrations and depth (Figure 4.12).

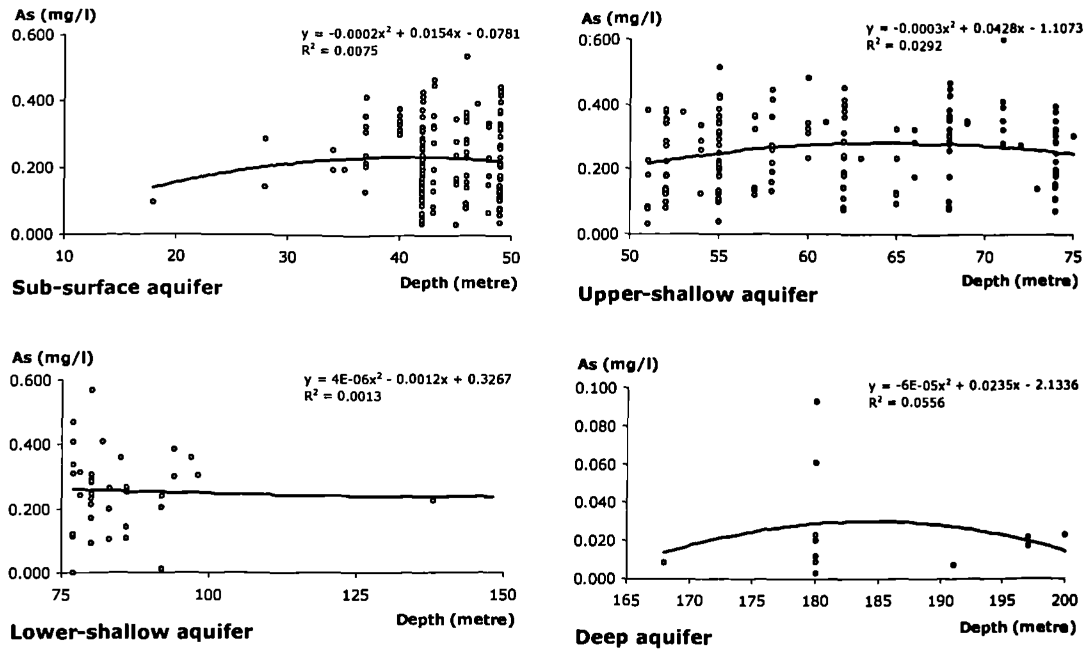


Figure 4.12: Relationships between depth and arsenic with polynomial trend.

At the lower-shallow aquifer the value ($r = -0.035$) designates a low negative relationship with arsenic, i.e. between 76-150 metres depth, arsenic concentrations slowly decrease with the increase of depth; while in the deep aquifer the value ($r = -0.0789$) also specifies a low negative relationship with arsenic concentrations (Table 4.5 and Figure 4.12). Only 17% of tubewells (2 out of 12) are found to be contaminated at a low level (between 0.05 and 0.1 mg/l) in the deep aquifer; while 83% (10 out of 12) are found to be safe.

4.3.2 What kind of regional variation exists in arsenic-depth relation?

The study area experiences a regional variation of arsenic concentrations with aquifer depths. The pattern of arsenic concentrations does not vary with depth, but the relationships between arsenic-depth and regional context also show a considerable contrast. In the broad category of shallow aquifer zone, arsenic concentrations range from 0.034 mg/l at 42 metres depth in Ward-2 to 0.535 mg/l at 46 metre depth in Ward-7 at the sub-surface aquifer; at the upper-shallow aquifer the concentration ranges between 0.032 mg/l at 51 metres depth in Ward-6 and 0.600 mg/l at 71 metre depth in Ward-7; while at the lower-shallow aquifer the concentration ranges between 0.011 mg/l at 92 metres depth in Ward-6 and 0.568 mg/l at 80 metres depth in Ward-7 (Field Survey, 2001). It is noted that there are no tubewells tapping the deep aquifer in Wards-1, 2 and 7 (Table 4.4) and in this aquifer the arsenic concentrations range between <0.003 mg/l at 180 metres depth in Ward-9 and 0.093 mg/l at 180 metres depth in Ward-6.

The correlation coefficient values between arsenic concentrations and depths and the scatter diagrams with polynomial trend lines for different administrative wards suggest the relationships between arsenic concentrations and depths of different strengths (Figure 4.13). From the correlation coefficient values, we have found a low positive relationship between aquifer depths and arsenic concentrations in Ward-7 ($r=+0.27$) followed by Ward-1 ($r=+0.22$) and Ward-2 ($r=+0.02$); low negative relationships are found in Ward-5 ($r=-0.28$) followed by Ward-3 ($r=-0.20$), Ward-8 ($r=-0.19$) and Ward-6 ($r=-0.14$); while weak moderate negative relationships are found in Ward-9 ($r=-0.50$) and Ward-4 ($r=-0.49$). The survey as a whole yielded a weak negative relation between aquifer depths and arsenic concentrations in the study area.

Why this variation in arsenic-depth relationships? It has already been pointed out from the relevant literature that arsenic concentrations are said to decrease with increasing aquifer depth. But, this study shows different aspects in the arsenic-depth relationships. These regional variations of arsenic concentrations

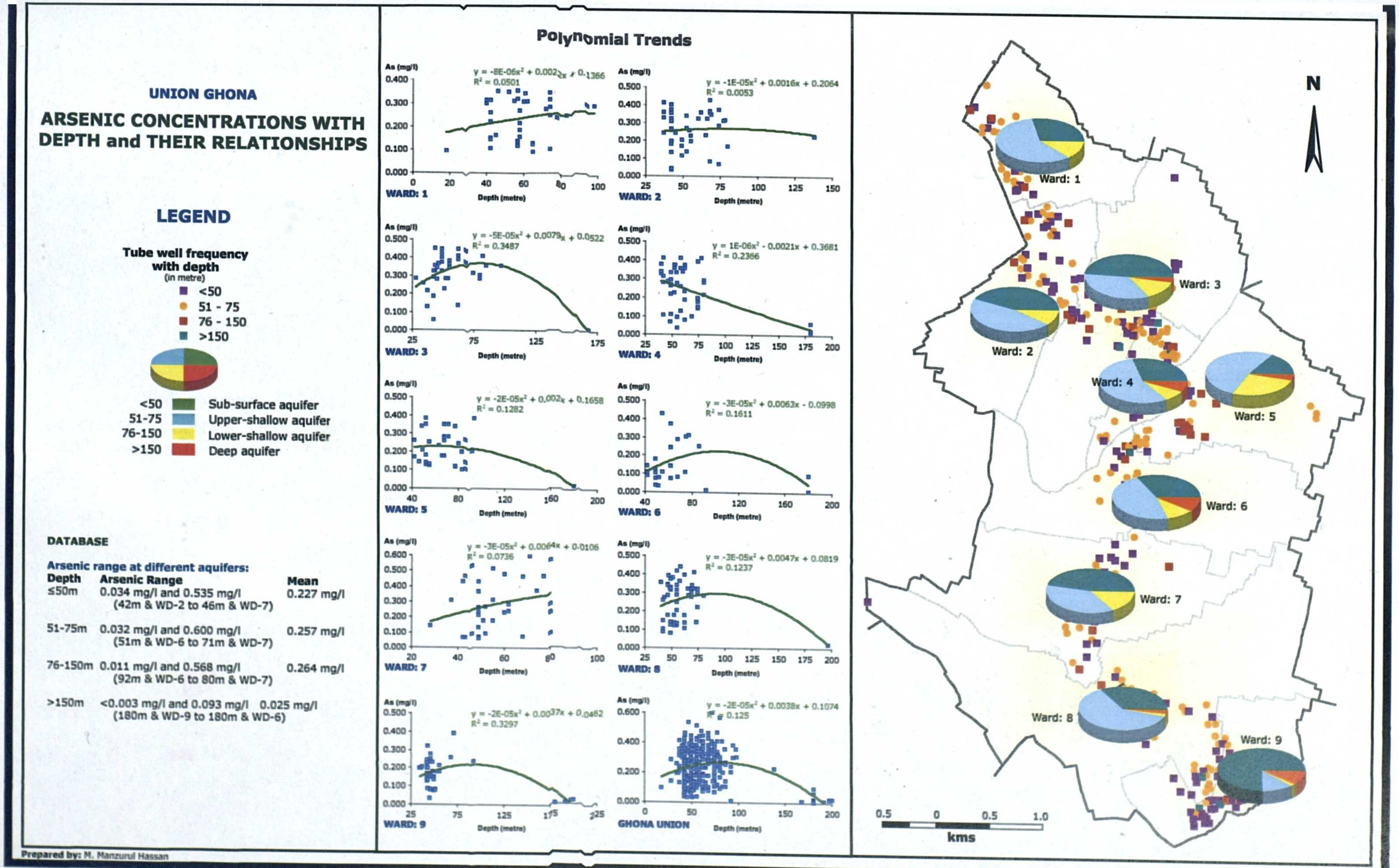

UNION GHONA
ARSENIC CONCENTRATIONS WITH DEPTH and THEIR RELATIONSHIPS
LEGEND
Tube well frequency with depth (in metre)
<50
51 - 75
76 - 150
>150
<50 Sub-surface aquifer
51-75 Upper-shallow aquifer
76-150 Lower-shallow aquifer
>150 Deep aquifer
DATABASE
Arsenic range at different aquifers:
Depth Arsenic Range Mean
≤50m 0.034 mg/l and 0.535 mg/l (42m & WD-2 to 46m & WD-7) 0.227 mg/l
51-75m 0.032 mg/l and 0.600 mg/l (51m & WD-6 to 71m & WD-7) 0.257 mg/l
76-150m 0.011 mg/l and 0.568 mg/l (92m & WD-6 to 80m & WD-7) 0.264 mg/l
>150m <0.003 mg/l and 0.093 mg/l (180m & WD-9 to 180m & WD-6) 0.025 mg/l
Polynomial Trends
WARD: 1
y = -8E-06x² + 0.002x + 0.1366
R² = 0.0501
WARD: 2
y = -1E-05x² + 0.0016x + 0.2064
R² = 0.0053
WARD: 3
y = -5E-05x² + 0.0079x + 0.0522
R² = 0.3487
WARD: 4
y = 1E-06x² - 0.0021x + 0.3681
R² = 0.2366
WARD: 5
y = -2E-05x² + 0.002x + 0.1658
R² = 0.1282
WARD: 6
y = -3E-05x² + 0.0063x - 0.0998
R² = 0.1611
WARD: 7
y = -3E-05x² + 0.0064x + 0.0106
R² = 0.0736
WARD: 8
y = -3E-05x² + 0.0047x + 0.0819
R² = 0.1237
WARD: 9
y = -2E-05x² + 0.0037x + 0.0462
R² = 0.3297
GHONA UNION
y = -2E-05x² + 0.0038x + 0.1074
R² = 0.125
As (mg/l)
Depth (metre)
N
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
0.5 0 0.5 1.0
kms
Prepared by: M. Manzurul Hassan

Figure 4.13

with depth in different parts of the study area (administrative wards) probably follow the geological variability in the study area. In addition, it has been found that arsenic contaminated wells (>0.05 mg/l) seem to occur within the depth range of 20-100 metres in the study area.

4.3.3 How uneven is arsenic variation with depth?

It has already been shown that arsenic concentrations are highly uneven with depth. It can be seen that the maximum arsenic concentrations are experienced within the shallow aquifer; while minimum concentrations are found in the deep aquifer (Table 4.4). In this subsection a paradoxical arsenic concentration with certain depths has been shown.

At a depth of 42 metres (sub-surface aquifer), a sharp variation in arsenic concentrations is identified in 51 tubewells, having a range of between 0.034 mg/l in Ward-2 and 0.428 mg/l in Ward-7, with a mean $(\overline{X})$ concentration of 0.2035 mg/l and a standard deviation (δ_n) of 0.0988 (Table 4.6). The high nugget effect (0.003136) shows a substantial variability of arsenic concentrations at this depth (Figure 4.14). In Ward-2, there have been found 6 tubewells located within a radius of about 215 metres of each other having arsenic concentrations of between 0.179 mg/l and 0.375 mg/l; while 9 tubewells have been found in Ward-9 within a 135 metre radius that have values between 0.142 mg/l and 0.241 mg/l (Table 4.6 and Figure 4.14).

At a depth of 55 metres (upper-shallow aquifer), a substantial variability in arsenic concentrations for 28 tubewells is also found between 0.037 mg/l in Ward-4 and 0.515 mg/l in Ward-7, with a mean $(\overline{X})$ of 0.2542 mg/l and a standard deviation (δ_n) of 0.1176 (Table 4.6). At the boundary line of Ward-5 and 6, there have been identified 4 tubewells located within a radius of about 135 metres having readings between 0.108 mg/l and 0.251 mg/l (Figure 4.14). Moreover, the nugget effect (0.006406) shows a significant inconsistency of arsenic concentrations at this depth (Figure 4.14).

Table 4.6.
Pattern of arsenic concentrations and variation at selected aquifer depths in the study area.

Selective depth (metre)	**F**	**Arsenic range** (mg/l)	**Mean arsenic** (mg/l)	**Standard deviation**	**Pointing circle radius** (metre)	**Frequency** (circle)	**Arsenic range in pointing circle** (mg/l)	**Mean arsenic at circle** (mg/l)
42	51	0.034 – 0.428 (WD: 1 & WD: 7)	0.2035	0.0988	WD-2: 215 WD-9: 135	WD-2: 6 WD-9: 9	WD-2: 0.179 – 0.375 WD-9: 0.142 – 0.241	WD-2: 0.290 WD9: 0.194
49	41	0.036 – 0.446 (WD: 6 & WD: 3)	0.170	0.1179	WD-7: 210 WD-8: 160	WD-7: 5 WD-8: 4	WD-7: 0.061 – 0.266 WD-8: 0.040 – 0.321	WD-7: 0.181 WD-8: 0.167
52	22	0.079 – 0.383 (WD: 6 & WD: 5)	0.2314	0.1058	-	-	-	-
55	28	0.037 – 0.515 (WD: 4 & WD: 7)	0.2542	0.1176	Between WD-5 & 6: 135	TW: 4	0.108 – 0.251	0.153
62	23	0.073 – 0.446 (WD: 6 & WD: 3)	0.2617	0.1182	-	-	-	-
68	21	0.076 – 0.464 (WD: 7 & WD: 7)	0.2801	0.1180	-	-	-	-
74	25	0.069 – 0.392 (WD: 2 & WD: 4)	0.2365	0.0955	WD-4: 80	WD-4: 7	WD-4: 0.142 – 0.196	0.163
80	12	0.092 – 0.568 (WD: 7 & WD: 7)	0.271	0.1120	-	-	-	-
180	7	<0.003 – 0.093 (WD: 9 & WD: 6)	0.031	0.0330	WD-4: 350	WD-4: 3	WD-4: 0.012 – 0.061	0.032

Data Source: Field Survey, 2001.
Figures in the parentheses indicate the Ward number. Here WD stands for the administrative ward.

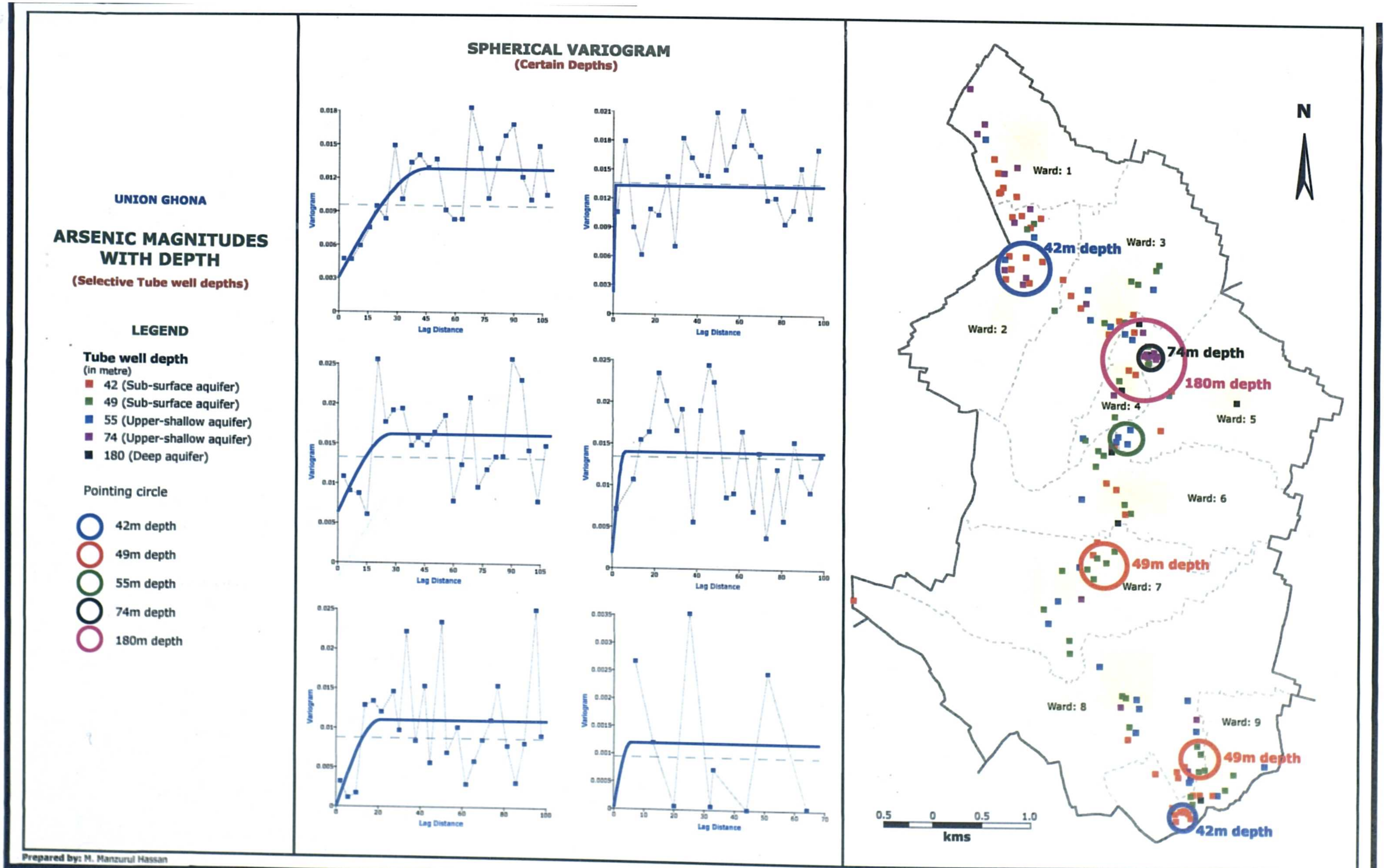

UNION GHONA
ARSENIC MAGNITUDES WITH DEPTH
(Selective Tube well depths)
LEGEND
Tube well depth
(in metre)
42 (Sub-surface aquifer)
49 (Sub-surface aquifer)
55 (Upper-shallow aquifer)
74 (Upper-shallow aquifer)
180 (Deep aquifer)
Pointing circle
42m depth
49m depth
55m depth
74m depth
180m depth
SPHERICAL VARIOGRAM
(Certain Depths)
Variogram
Lag Distance
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
42m depth
74m depth
180m depth
49m depth
49m depth
42m depth
N
0.5
0
0.5
1.0
kms
Prepared by: M. Manzurul Hassan

Figure 4.14

At the depth of 180 metres (deep aquifer), dissimilarity in arsenic concentrations was also found for 7 tubewells having a range of <0.003 mg/l in Ward-9 to 0.093 mg/l in Ward-6, with a mean $(\overline{X})$ of 0.031 mg/l and a standard deviation (δ_n) of 0.033 (Table 4.6). A nugget effect close to zero shows a low arsenic variation at this depth (Figure 4.14).

The high variation of nugget effect for arsenic concentrations with specific aquifer depths shows a high variability of arsenic magnitudes (Figure 4.14). The sharp regional variation of arsenic concentrations in the same aquifer raises different questions. Is geological variability the main cause of the differences or are there other factors in this regard? It has been found from this study that the most affected aquifers lie beneath the Ganges floodplains of the study area. In addition, the variation of arsenic magnitudes with depth suggests that within the zone of water table fluctuation and where residence times are shortest, arsenic is being either flushed away or immobilized (BGS, 1999).

4.4 ARSENIC MAGNITUDES WITH TIME

This section considers the temporal relationship between arsenic concentrations and installation year of tubewells. Tubewells were first installed in the study area in 1950 and there were 6 tubewells prior to the 1971 Liberation War. The number of tubewells increased slowly during the Skeikh Mujibur Rahman Regime (1972-75) and the General Ziaur Rahman Regime (1976-81). At the end of General Ershad's government (1982-1990) the total number of tubewells had increased to 144 (Table 4.7). The tubewells continued to increase in number afterwards. Under the Khaleda Zia Regime (1991-96), they grew to 253 and at the end of the Sheikh Hasina Regime (1996-2001) to 375 (Table 4.7).

There is a variation in arsenic concentrations found with time of tubewell installation. The oxidation theory shows that arsenic concentrations will increase if there is a heavy withdrawal of groundwater from the aquifer over time

Table 4.7.
Ward-wise geographical distribution of tubewells with installation year.

Major Categories	Inst. Year	Different Regimes	Tube wells in different Words										Safe Level	Cont. Level
			WD-1	WD-2	WD-3	WD-4	WD-5	WD-6	WD-7	WD-8	WD-9	Total		
Pre-Liberation	1971 and earlier	Pakistan Period	1 (0.27)	-	-	-	1 (0.27)	-	1 (0.27)	-	3 (0.80)	**6** (1.60)	-	6 (1.60)
Post-Liberation	1972-1975	Sheikh Muzib regime	1 (0.27)	1 (0.27)	-	1 (0.27)	-	-	2 (0.53)	-	2 (0.53)	**7** (1.87)	-	7 (1.87)
	1976-1981	General Zia regime	-	1 (0.27)	-	3 (0.80)	2 (0.53)	-	1 (0.27)	2 (0.53)	1 (0.27)	**10** (2.67)	-	10 (2.67)
	1982-1990	General Ershad regime	8 (2.13)	20 (5.33)	14 (3.73)	17 (4.53)	9 (2.40)	09 (3.40)	9 (2.40)	11 (2.93)	24 (6.40)	**121** (32.27)	4 (1.07)	117 (31.20)
	1991-1996	Khaleda Zia regime	9 (2.40)	10 (2.67)	14 (3.73)	18 (4.80)	8 (2.13)	8 (2.13)	12 (3.20)	20 (5.33)	10 (2.67)	**109** (29.07)	4 (1.07)	105 (28.00)
	1996-2000	Sheihk Hasina regime	19 (5.07)	13 (3.47)	11 (2.93)	14 (3.73)	16 (4.27)	09 (2.40)	11 (2.93)	20 (5.33)	9 (2.40)	**122** (32.53)	9 (2.40)	113 (30.13)
		GHONA Total	**38** (10.13)	**45** (12.00)	**39** (10.40)	**53** (14.13)	**36** (9.60)	**26** (6.93)	**36** (9.60)	**53** (14.13)	**49** (13.07)	**375** (100)	**17** (4.53)	**358** (95.47)

Data Source: Field Survey, 2001.
Figures in the parentheses indicate the net percent of the sample TWs and the dataset are classified on the basis of mainly the *different* regimes.
(The arsenic concentration in tube wells is <0.05 mg/l is recognised as the **safe level**; while the value for 0.05 mg/l and more is known as the **contamination level**).

(Acharyya, 1997; Appelo and Postma, 1996; and Das *et al*, 1995). This research shows that all 23 tubewells installed prior to 1981 are now experiencing contamination with arsenic to different degrees (Table 4.8). The mean for the 121 tubewells dating from 1982 to 1990 is 0.2145 mg/l with only 4 tubewells found to be safe (Table 4.8). The further 109 tubewells installed between 1991 and 1996 have a mean concentration of 0.260 mg/l, about one-third ($n = 39$) of them are within the severe contamination category and only 4 tubewells are found to be safe (Table 4.8). Recently (1996-2000) 122 more tubewells have been installed and 113 of them are contaminated; while only 9 tubewells were safe (Table 4.8). It is noted that there were none of the safe tubewells in the study area were installed prior to 1981 (Table 4.8).

It is calculated from the GLMs that at the 95% confidence level with a standard error of 0.019072, there is a very low positive correlation ($r = +0.208$) between the installation year of each tubewell and arsenic concentrations. Figure 4.15 shows the analogous corresponding relation between the tubewell installation years and arsenic concentrations. The inverse quadratic trend line shows a very slight increasing trend of arsenic concentrations from the year 1950; while the lowess trend line shows more or less the same with the inverse quadratic trend with little fluctuation (Figure 4.15).

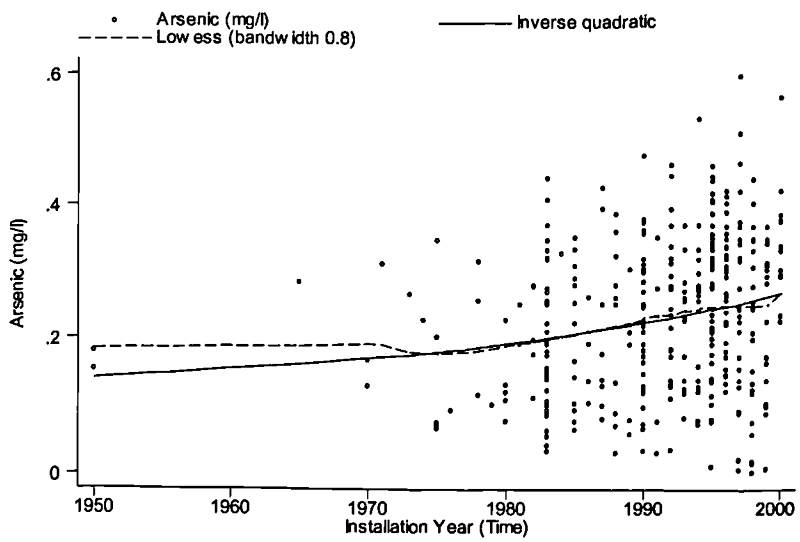


Figure 4.15: Generalised Linear Models between installation year of tubewells and arsenic relationships.

Table 4.8.
Geographical distribution of arsenic with installation year and descriptive statistics.

Installation year	Arsenic magnitudes					Overall picture					
	Safe Level		Contamination Level			Safe Level		Contamint. Level		Total	
	<0.01	0.01-0.05	0.05-0.1	0.1-0.3	>0.3	F	Statistics	F	Statistics	F	Statistics
1971 & earlier	-	-	-	5 (1.33)	1 (0.27)	-	-	6 (1.60)	-	6 (1.60)	**0.2045** *+0.343*
1972-1975	-	-	3 (0.80)	3 (0.80)	1 (0.27)	-	-	7 (1.87)	-	7 (1.87)	**0.183** *+0.421*
1976-1981	-	-	02 (0.53)	07 (1.87)	01 (0.27)	-	-	10 (2.67)	-	10 (2.67)	**0.1582** *-0.1486*
1982-1990	-	4 (1.07)	15 (4.00)	73 (19.47)	29 (7.73)	04 (1.07)	-	117 (31.20)	**0.209** *+0.014*	121 (32.27)	**0.2145** *+0.1335*
1991-1996	-	4 (1.07)	7 (1.87)	59 (15.73)	39 (10.40)	4 (1.07)	**0.023** *-0.938*	105 (28.00)	**0.2605** *+0.1059*	109 (29.07)	**0.2518** *+0.1173*
1996-2000	4 (1.07)	5 (1.33)	5 (1.33)	53 (14.13)	55 (14.67)	9 (2.40)	**0.0146** *-0.5450*	113 (30.13)	**0.2795** *+0.0116*	122 (32.53)	**0.260** *-0.0177*
GHONA Total:	4 (1.07)	13 (3.47)	32 (8.53)	198 (52.80)	127 (33.87)	17 (4.53)	**0.0217** *-0.8117*	358 (95.47)	**0.248** *+0.2699*	375 (100.00)	**0.238** *+0.208*

Data Source: Field Survey, 2001.
Figures in the parentheses indicate the net percent of the sample tubewells. The **bold** figures represent the average arsenic concentration of tubewells at the respective installation years; while the *italic* figures are for correlation co-efficient (**r**) values between arsenic concentrations and installation year of tubewells.

To assess the relationships, the arsenic concentration of each tubewell was plotted against the installation year of each tubewell for different periods (Table 4.8 and Figure 4.16). The correlation coefficient value ($r = +0.2133$) for the tubewells installed prior to 1981 indicates a low positive relationship with arsenic concentrations (Figure 4.16). For the installation years of 1982-90 and 1991-96 the r values indicate a low positive relationship; while in the years 1996-2000 the value indicates a low negative relationship with arsenic concentrations (Table 4.8).

From the spatial distribution of arsenic concentration with the installation years of tubewells, it seems that there is a weak correlation between the occurrence of arsenic and the installation year of tubewells. It is found from the study area that since people are continuing to withdraw groundwater mainly for irrigation purposes, this could be the cause of arsenic entering into groundwater. The GLM trend line shows a slight increase of arsenic with time, indicating that the more withdrawal the groundwater the more arsenic will concentrate.

4.5 ARSENIC EXPOSURE: CHRONIC HEALTH EFFECTS

What kind of health impacts are posed by arsenic? The health effects of arsenic from drinking water appear slowly. If the population continues to ingest arsenic contaminated drinking water, there is a possibility that arsenicosis symptoms will appear in the human body. Arsenic contamination of the environment has received much attention due to toxicological evidence of its potential human health hazards, e.g., skin diseases including an enhanced skin cancer risk potential, liver disturbances, heart diseases etc., even at lower levels of exposure (Abernathy *et al*, 1997). The most deceptive and dangerous aspect of arsenic toxicity is its very slow and insidious development. It is reported from various published sources that low exposures of inorganic arsenic in drinking water can be the cause of cancer.

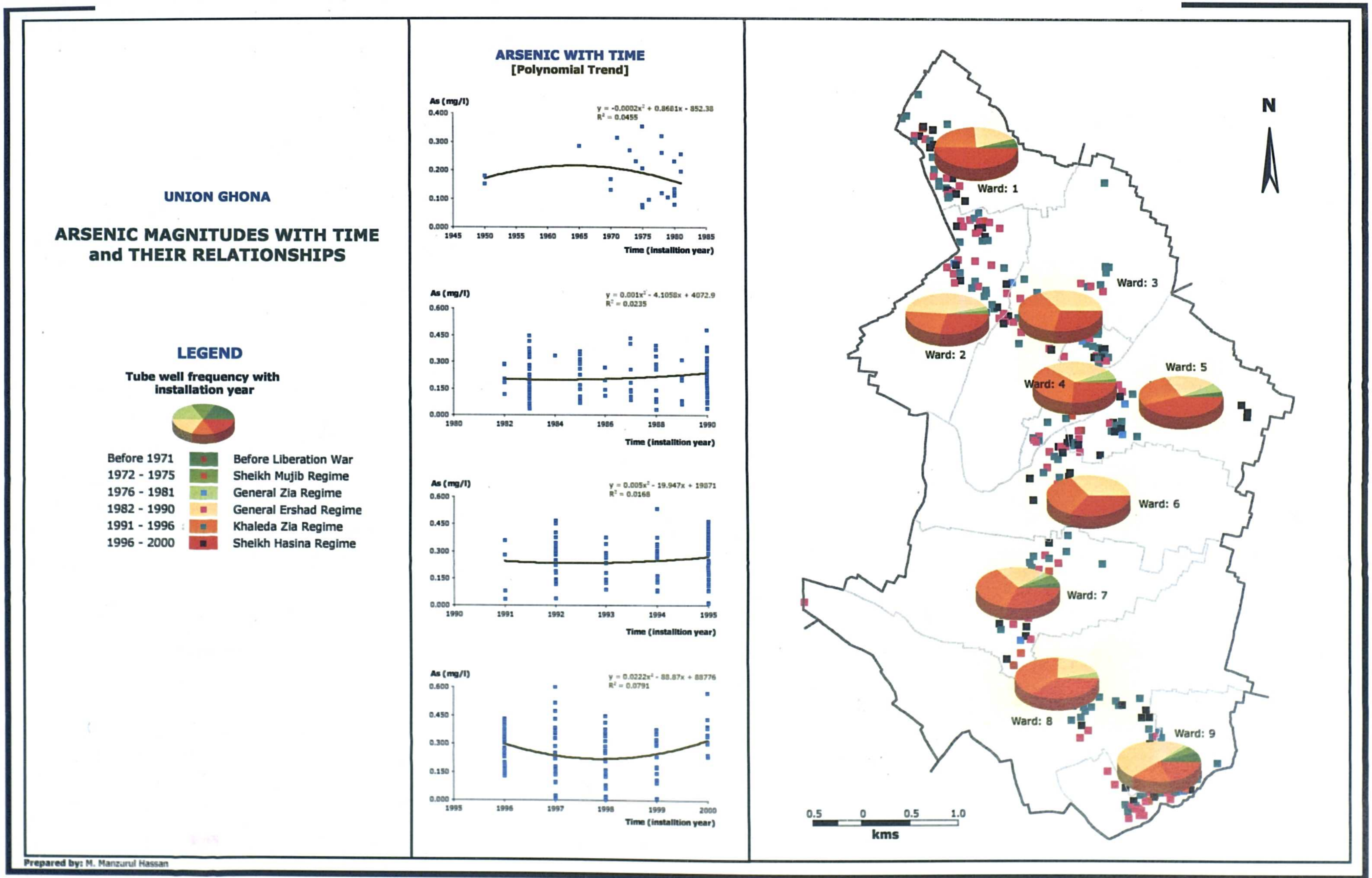

UNION GHONA
ARSENIC MAGNITUDES WITH TIME and THEIR RELATIONSHIPS
LEGEND
Tube well frequency with installation year
Before 1971 Before Liberation War
1972 - 1975 Sheikh Mujib Regime
1976 - 1981 General Zia Regime
1982 - 1990 General Ershad Regime
1991 - 1996 Khaleda Zia Regime
1996 - 2000 Sheikh Hasina Regime
ARSENIC WITH TIME
[Polynomial Trend]
As (mg/l)
Time (installtion year)
N
Ward: 1
Ward: 2
Ward: 3
Ward: 4
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
0.5 0 0.5 1.0
kms
Prepared by: M. Manzurul Hassan

Figure 4.16

The arsenic hazard gives Bangladesh a new dimension to its existing plethora of natural calamities. Groundwater is highly polluted by arsenic and at present two-thirds of the population are at risk of arsenic contamination (Ahmed, 1999; Alam, 1998; Bearak, 1998; Chowdhury, 1997; Dhar *et al*, 1998; Hussain, 1999; and Nickson *et al*, 2000). It is also estimated that at least 1.2 million people are exposed to arsenic poisoning (Karim, 2000). The scale of this environmental disaster is greater than any seen before; it is of greater significance than the accidents at Bhopal in 1984, and Chernobyl in 1986 (Smith *et al*, 2000a). A health impact of ingesting arsenic from groundwater has been found in the study area and will be explored in this section.

4.5.1 Skin lesions and non-malignant health effects

Arsenic toxicity starts in the human body when it is exposed to an excessive quantity. It is estimated that about 5-15 years are required in developing chronic arsenicosis symptoms and over time the symptoms become more pronounced. In some cases internal organs including the liver, kidneys and lungs can be affected (WHO, 1996). Chronic exposure to low levels of arsenic causes different types of skin lesions. The apparent symptoms of arsenicosis are manifested mainly in the form of melanosis, leuco-melanosis and keratosis and appear on the hands and feet (Col *et al*, 1999; Jaafar *et al*, 1993; Guha Mazumder *et al*, 1998a; and Tondel *et al*, 1999). Moreover, exposure to arsenic in drinking water is associated with non-carcinogenic as well as non-malignant health effects such as diabetes (Lai *et al*, 1994; Rahman *et al*, 1999a; and Tondel *et al*, 1999), peripheral neuropathy (Chiou *et al*, 1997), cardiovascular diseases (Engel and Smith, 1994), ischemic heart disease-ISHD (Chen *et al*, 1996 and Hsueh *et al*, 1998), hypertensive heart disease (Lewis *et al*, 1999), and bronchitis (Abernathy *et al*, 1999).

Several years (about 5-15 years) of low level to high level of continuous arsenic exposure may cause various skin lesions. The latency for arsenic-caused skin lesions is typically about 10 years (Guha Mazumder *et al*, 1998b). Daily consumption of water with more than 0.05 mg/l of arsenic can lead to problems with the skin and circulatory and nervous systems (Das *et al*, 1996). It is not clear from the literature how much ingestion of arsenic causes what types of skin lesions. My study identified 2 patients with skin lesions, in particular, melanosis, who had been ingesting arsenic <0.05 mg/l for around 10-15 years. We identified 2 patients to be affected by skin lesions, with the symptoms of melanosis, who were ingesting arsenic between 0.05 mg/l and 0.1 mg/l for the last 20 years in the study area; while 5 patients were found to be affected with keratosis, having ingested arsenic at more than 0.1 mg/l for the last 15-20 years. Figure 4.17 shows the pathological manifestations on bodies of arsenic affected people.

Arsenic lesion on hand   Arsenic lesion on feet   Arsenic lesion on chest

Figure 4.17: Pathological manifestation on the bodies of arsenic affected people.
Source: Field Survey, 2001.

4.5.2 Malignant health effects

If arsenic builds up to higher toxic levels, organ cancers, neural disorders, and organ damage – often fatal – can result. Several lines of evidence indicate that the genotoxic effects of arsenic may lead to carcinogenesis. Cancer risks from inorganic arsenicals in drinking water have been proved and reported (Brown and Chen, 1995; Chatterjee and Mukherjee, 1999; Hsueh *et al*, 1995; Gou and Lu, 1994; Mushak and Croeetti, 1995; Tseng *et al*, 1995 and Woollons and Russel-Jones, 1998). In the most severe cases, cancer can occur in the skin and internal organs, and limbs can be affected by gangrene (UNICEF, 2000).

A few years of continued exposure to low levels of inorganic arsenicals causes different skin lesions, and after about 10-15 years these turn into skin cancers (Byrd *et al*, 1996). It is reported from various reports and published articles that after a latency period of 20-30 years, internal cancers, particularly of the bladder and lung, could appear. Tsuda *et al* (1995) also indicate the high mortality rate of urinary tract cancer as the long-term effect of exposure to ingested arsenic with a cohort study followed for 33 years in Japan. In my work we identified one patient with worse skin lesions, in particular, hyperkeratosis, who were ingesting arsenic 0.446 mg/l for around 18 years and one person also identified with gangrene due to the impact of arsenic (Figure 4.18). This man had been ingesting arsenic at 0.353 mg/l for about 26 years.

Arsenic lesions on hand, extreme   Arsenic lesions on foot, gangrene

Figure 4.18: Extreme pathological manifestation of arsenicosis.
Source: Field Survey, 2001.

Chronic arsenic toxicity affects the skin, nervous system, liver, cardiovascular system and respiration tract (Del Razo *et al*, 1997). Tsuda *et al* (1995) also think that an exposure of 5 years of a high dose of arsenic (>0.1 mg/l) can cause skin signs of chronic arsenicism for subsequent cancer development. While, Buchet and Lison (1998) investigate the dose-response relationship for lung carcinoma and other cancers at low doses of arsenic, concluding that a low to moderate level of environmental exposure to inorganic arsenic (0.02-0.05 mg/l) from drinking water does not have any dose-response relationship with cancer. From the study of the chronic arsenic effects on health, it has been found that only 11 patients have been identified from a population of about 11,000 with different levels of arsenicosis. It is noted that we found a family of all whose members were affected with arsenicosis (Figure 4.19). All the identified patients were ingesting arsenic with more or less same toxicological levels. It is found from this study that no patients have been identified with cancer symptoms.

Affected Family (Gazi Family) | Arsenic lesion on hands (Mr. A Ali Gazi) | Mrs Marrium Gazi | Ms. Bilquis Ara Khatun

Master Alam Gazi | Arsenic lesion on feet (Mr Gazi) | Arsenic lesion on feet (Mrs Gazi) | Arsenic lesion on feet (Master Alam)

Figure 4.19: An arsenic affected family.
Source: Field Survey, 2001.

Why are so few people affected with arsenicosis in the study area when more than 95% of the tubewells are contaminated with arsenic? The answer to this question depends mainly on the water condition attributes of tubewells. In the study area 62% ($n = 233$) of tubewells were found to be completely dry during the summer, 20% ($n = 76$) were found to have a small amount of water; while 18% ($n = 66$) were found to have water available during the summer (Table 4.9).

During the summer, most people change their regular practice and use the tubewells where water is available. About 15% ($n = 56$) of the net tubewells

Table 4.9.
Geographical distribution of arsenic with tubewell water conditions.

Water conditions	Arsenic magnitudes					Overall picture					
	Safe Level		Contamination Level			Safe Level		Cont. Level		Total	
	<0.01	0.01-0.05	0.05-0.1	0.1-0.3	>0.30	F	Mean	F	Mean	F	Mean
Available water	4 (1.07)	6 (1.60)	8 (2.13)	28 (7.47)	20 (5.33)	10 (2.67)	0.0144	56 (14.93)	0.2466	66 (17.60)	0.2114
A little bit water	-	1 (0.27)	6 (1.60)	45 (12.00)	24 (6.40)	1 (0.27)	-	75 (20.00)	0.2379	76 (20.27)	0.2352
No water	-	6 (1.60)	18 (4.80)	123 (32.80)	86 (22.93)	6 (1.60)	0.0322	227 (60.53)	0.2521	233 (62.13)	0.2464

Data Source: Field Survey, 2001.
(Figures in the parentheses indicate the net percent of the sample tubewells).

were found to be contaminated and only 2.67% ($n=10$) were safe in this category (Table 4.9). The author in the study area found queues of people collecting drinking water from the deep tubewells. Since there is an intermittent practice in collecting water from DTWs, this might be one factor in keeping people at a lower risk. People who use water from contaminated tubewells are those mainly affected with health problems. A major portion of the population is affected with chronic indigestion. Malnutrition, poor socio-economic conditions, and unbalanced food habits of the people aggravate the hazards of arsenic toxicity. Moreover, the period differs from patient to patient depending on the nutritional status of the person, and the amount and total time of arsenic ingestion.

4.6 RISK CHARACTERISATION: ASSESSMENT AND SPATIAL RISK ZONING

How many people are at risk and at which level? Or, which areas are at risk and which areas are safe? In an attempt to answer these questions, a risk assessment model and a spatial risk zoning model were developed. Before analysing the risk objectives, we need to deal with the terminological issues of risk, hazard, and toxicity since there are many equivocal concepts regarding these terminologies (Cohrssen and Covello, 1989; and Kates, 1985).

Risk can be considered as the possibility of suffering harm from a hazard, where, in this case, the hazard is the harm from arsenic to human health. Toxicity refers to the inherent potential of arsenic to cause systemic damage (Kates, 1985). It is noted that the term hazard is not a synonym for toxic. Risk assessment refers to the process of estimating the magnitude of risk to human health posed by exposure to arsenic as an environmental hazard in the study area. The assessment of environmental health risk is based on a combination of information on the amount of arsenic people were exposed to and its toxicity; while spatial risk assessment concerning arsenic toxicity is involved in mapping the areas of affected people and those likely to be affected in future as a result of ingesting different levels of arsenic.

4.6.1 Risk assessment parameters

There is growing concern about levels of arsenic in the environment because of its toxic nature to human body. Is it safe to drink tubewell water? Will any one get any arsenicosis symptoms if s/he drinks that water? To answer these questions, requires a toxicological risk assessment, with an exposure assessment and a toxicity assessment. Figure 4.20 shows a general method for assessing the environmental health risk of arsenic in the study area.

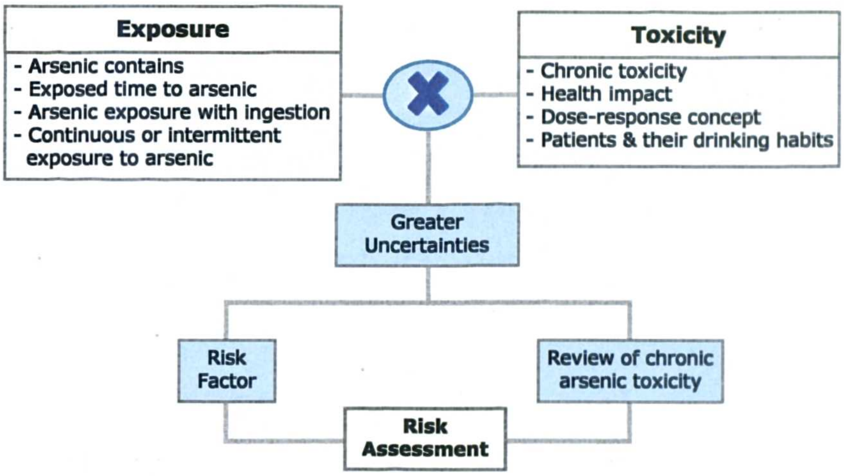


Figure 4.20: Method of assessing the environmental health risk of arsenic in the study area.

Exposure Assessment: How much arsenic is an individual or population exposed to? The exposure assessment depends on: (a) how much arsenic is present in the groundwater; (b) how long people have been exposed to arsenic; (c) whether the exposure was continuous or intermittent; and (d) how the people were exposed (http://www.facsnet.org/tools/ref_tutor/risk/index.php3). Since the people of the study area are fully dependent on tubewell water for their drinking and cooking purposes, we need to analyse the concentrations of arsenic in the tubewells and how long tubewells have been there.

In measuring the chronic exposure to arsenic, I analysed arsenic concentrations for all the drinking tubewells in a straightforward process. By the FI-HG-AAS laboratory method, the amount of arsenic has been estimated that was present in the groundwater. I also measured how long tubewells have been there. Then a calculation was made of how many people were exposed by asking the tubewell holder a question about how many people collect water from this tubewell in a day. After the amount of arsenic in a tubewell water is assessed, the route of exposure (ingestion) was determined and the amount that people consumed was then estimated. It is noted that the tubewell water is mainly used for drinking and cooking purposes.

An exposure assessment is stated in terms of the likelihood that people are exposed to a given level of arsenic over a specified period of time. In our example, if groundwater that is used for drinking and cooking purposes is found to have arsenic at 0.01 mg/l, a person who drinks 2 litres of water and cooks 1 litre of water each day will have an exposure of 30 mg/day from this source. This figure is always changing, thus, an exposure assessment is stated in terms of the likelihood.

Toxicity Assessment: Toxicity assessment refers to the investigation of the potential for arsenic to cause harm and how much arsenic causes what kind of harm. Toxicity to humans is not usually measured directly. Arsenic is toxic in quantity, but the mere presence of arsenic does not automatically imply harm. This is why toxicity assessment is concerned with the type and degree of harm caused by differing amounts of arsenic. The chronic effects happen only after repeated long-term exposure (ingesting arsenic with low levels of contaminants).

The dose-response concept is the basis of all toxicity assessments: as the dose (exposure) increases, the response (toxicity) increases. Scientists perform studies to determine exactly how high a dose causes what kind of a response, or effect. The smaller the dose needed to cause an effect, the more potent (toxic) the substance is. Here the author examined the relationships between the arsenicosis patients, their habits in drinking water, and the time of exposure to arsenic contaminated drinking water. The author is also keeping in mind the outcome of chronic arsenic toxicity to human health.

4.6.2 Arsenic risk pattern

What is the risk posed by arsenic in its present use patterns from groundwater? In risk characterisation, I combined information on exposure and toxicity to estimate the type and magnitude of arsenic risk faced by the exposed population. Combining the evaluation of arsenic toxicity with estimates of how much people are exposed leads to an assessment of the risk pattern. Apart from this, the combination of different arsenic data in relation to the installation year of tubewells and the number of people who ingest water from the tubewells helps to identify exposure patterns to arsenic from tubewell water as a factor of risk assessment (Figure 4.20).

It is clear from this discussion that combining the uncertainties of toxicity assessment with the uncertainties of exposure assessment will lead to an overall risk assessment with greater uncertainty than that associated with either the toxicity or the exposure estimates. Thus, it is not possible to describe the pattern of exact risk. But, we can assess how high and how low it could possibly be. The estimation of environmental health risk with uncertainties in this thesis is described within a range of probabilities and should be seen as a 'best guess', rather than an irrefutable statement of fact.

(a) The risk ratio, found by comparing the occurrence of arsenicosis symptoms with different toxic levels of arsenic, can be described as the process of estimating the environmental health risk from arsenic (Table 4.10). A risk ratio close to 1 suggests that there is no health effect from arsenic; a risk ratio of >1 suggests that the characteristic increases the risk of arsenicosis; and a risk ratio of <1 indicates that the characteristic protects against arsenicosis. It has been calculated that people who were ingesting arsenic between 0.01 and 0.05 mg/l daily were twice as likely to get arsenicosis symptoms as people who get arsenic at the safe level (<0.01 mg/l). Those who were ingesting arsenic at 0.05 – 0.1 mg/l daily were 4 times as likely to get arsenicosis symptoms; and who were ingesting arsenic at between 0.1 and 0.3 mg/l in a day were 6 times as likely to get the symptoms (Table 4.10). In addition, people who ingest arsenic at >0.3 mg/l are 11 times as likely to get arsenicosis symptoms as people exposed to <0.01 mg/l (Table 4.10).

Table 4.10.
Risk ratio/pattern of arsenic in the study area.

Ingesting arsenic (mg/l)	Identified patients	Exposure in years	Cumulative frequency	Risk ratio
<0.01	1	17	1	-
0.01-0.05	1	20-25	2	2/1=2
0.05-0.1	2	20	4	4/1=4
0.1-0.3	2	15-20	6	6/1=6
>0.3	5	>20	11	11/1=11

Source: Field survey, 2001.

(b) In identifying the arsenic risk, we need to consider the chronic impact of arsenic and to review the opinions or theories concerning the ingestion of arsenic contaminated drinking water and the associated health risks. Buchet and Lison (1998) concluded that a low to moderate level of environmental exposure to inorganic arsenic (0.02-0.05 mg/l) from drinking water does not have any dose-response relationship for arsenic and cancer. From the study area I found that even low exposures to inorganic arsenic (<0.05 mg/l) in drinking water can be the cause of arsenicosis symptoms and can increase health risk if the dose level contains <0.05 mg/l for a lifetime. In such cases, the risk of melanosis could be about 0.1% (1/1000).

(c) The WHO (1994) and the EPA (2001a) have issued different "Guideline Values" for arsenic ingestion in drinking water. Both set the maximum limit of taking arsenic at 0.01 mg/l; while the DoE (1994) has set the value at 0.05 mg/l for Bangladesh's standard maximum tolerable limit for groundwater arsenic. Daily consumption of water with more than 0.05 mg/l of arsenic can lead to problems with the skin and circulatory and nervous systems (Das *et al*, 1996). Apart from this, a recent study from Finland found that people who regularly drank >0.005 mg/l of arsenic had more than a 140% increase in bladder cancer rates compared to those who consumed levels of less than 0.001 mg/l (Kurttio *et al*, 1999). In my fieldwork we found a patient affected with arsenicosis symptoms after an exposure level of 0.01 mg/l for 17 years. This figure shows a chance of having health problems even at very low exposures.

(d) The EPA (2000a) has calculated that lifelong ingestion of 1 μg/kg/day (around 50 to 100 μg/day in an adult) is associated with a risk of skin cancer of about 0.1% (1/1000). This dose level is comparable to drinking water containing <0.05 mg/l for a life time. Using the same method, the risk of skin cancer estimates for 0.1 mg/l of arsenic in drinking water would be 2 per 1000 people (0.2% i.e. 2/1000).

(e) In analysing arsenic data from a study in an arseniasis-endemic area of Taiwan (Chen *et al*, 1988b; Chen *et al*, 1992; and Wu *et al*, 1989), Morales *et al* (2000) made a conclusion that although the shape of the exposure-response curve is uncertain at low levels of arsenic exposure, over a lifetime, one out of every 100-300 people who consume drinking water containing 0.05 mg/l arsenic may suffer an arsenic-related cancer (lung, bladder, or liver cancer) death. Smith *et al* (1992) predicted similar levels of arsenic risk.

Despite the considerable uncertainties in the underlying data, the risks are "sobering" (Morales *et al*, 2000). The low concentrations of waterborne arsenic are likely to cause harm to the human body (Foster, 2002). Morales *et al* (2000) made a conclusion that the lifetime risk of death is 1 in 100 from consuming 0.05 mg/l and 1 in 50 from consuming 0.1 mg/l of arsenic in drinking water. In view of this argument, it can be said that there is a chance that about 95 people will die with arsenicosis if they consume arsenic at 0.05 mg/l for lifetime; while 157 people will die with arsenicosis if they continuously intake arsenic for their lifetime at an 0.1 mg/l.

(f) It has been estimated that the lifetime risk of dying from cancer while drinking 1 litre of water a day containing arsenic at the concentration of 0.05 mg/l could be as high as 13 per 1000 people exposed (Smith *et al*, 1992). Using the same methods, the risk estimate for 0.1 mg/l of arsenic in drinking water would be 26 per 1000 people. The assessed risk for 0.2 mg/l of arsenic in drinking water would be 52 per 1000 people, rising to 130 per 1000 people if the concentration of arsenic in drinking water is 0.5 mg/l.

(g) Astolfi *et al* (1981) pointed out that a regular intake of drinking water containing >0.1 mg/l of arsenic leads to clearly recognisable signs of arsenic toxicity and ultimately in some cases to skin cancer. In view of this, it can be said that the risk estimate for >0.3 mg/l of arsenic in drinking water could be as high as 4 per 1000 people exposed for a life time.

(h) Tsuda *et al* (1995) claim that exposure for 5 years to a high dose of arsenic (>0.1 mg/l) can cause skin signs of chronic arsenicism and subsequent cancer development. By reviewing the present findings, we may suggest that there is a probability of 0.20% (20/1000) for getting cancer symptoms within 20 years if the exposure level exceeds 0.5 mg/l. But it is noted that no cancer patient was identified having the exposure to arsenic more than 0.5 mg/l for about 5 years. It is also noted that most of the people drink the arsenic-free water during the summer.

In view of the above description, it can be said that if people in the study area continue to ingest arsenic from groundwater, they might get arsenicosis symptoms and in some cases cancer can develop. Although the estimation of health risk in exposure to arsenic is uncertain, a low level of exposure to inorganic arsenic causes chronic toxicity in the body and will be related to health risks.

4.6.3 Defining spatial arsenic risk zones

Arsenic risk zones were mainly identified in a vector-base data analysis process by using GIS technology. A GIS was used as a platform enabling the management of the 'criterion data' (Store and Kangas, 2001) for the spatial risk zoning. GIS applications have frequently been used in producing new information, both by combining data from different sources and by the spatial analysis of existing data bases. The use of GIS methodologies in spatial environmental risk assessment has emerged and proliferated recently. GIS technology has been applied to a wide range of environmental risks. Several authors have reviewed the role of GIS in assessing risk (Carver, 1991; Dow, 1993; Emani, 1996; Gatrell and Vincent, 1991; McMaster and Johnson, 1987; and Newkirk 1993).

A GIS has strong spatial overlay capabilities that allows different map data to be combined in determining suitable sites for different risk zones of arsenic. In this section, the intention is mainly to integrate the map data using GIS PC OVERLAY techniques and also to develop a new spatial database for the risk zones. The spatial risk zoning processes were described as map layers within the GIS, and the map layers represented the exposure and toxicity. ArcGIS (version 8.1) was used to analyse the spatial arsenic risk zones.

A point-in-polygon operation through kriged interpolation methods was performed to analyse the spatial arsenic concentrations of different magnitudes. A cartographic model was developed in which the arsenic exposure data layer was created by combining the arsenic magnitudes map data, buffer area data of tubewell users, and the map data layer for tubewell installation years. The exposure data layer was then overlaid with the map data of the settlement area to yield a characterisation of different risk zones (Figure 4.21). On the basis of this method, the author developed the risk zones into four categories: (a) safe zones; (b) low risk zones; (c) medium risk zones; and (d) high risk zones. The four categories of risk zones were developed by poly-lines and they were converted to polygons using GIS in order to perform statistics. Note that the agricultural land was not accounted for in the spatial risk zoning.

(a) **Safe zone.** Here are the areas having concentrations of arsenic of <0.05 mg/l. The bounded isolines for this zone cover about 3.17% (7.70 hectares) of the total settlement area. The safe zones are located in the central (Ward-6) and southern (Ward-9) part of the study area (Figure 4.21). Only 10 tubewells are found in this category. A total of about 1760 people (16%) collect water from the tubewells located in this category all the year. During the summer, all of these 10 tubewells contain water and most of the people collect water from these tubewells.

(b) **Low risk zone.** Areas having arsenic concentrations between 0.05 and 0.10 mg/l and the installation years between 1981 and 2000 are categorised into this zone. The low risk zones are located in the northern (Wards - 1 and 2), central (Wards - 5 and 6) and southern (Wards – 8 and 9) part of the study area (Figure 4.21). The low risk zones cover about 4.18% (10.16 hectares) of total settlement area. A total of 12.50% (1375) of people collect water from 32 tubewells in this category. The author identified 2 arsenic affected patients from this low risk zone.

(c) **Medium risk zone.** Areas with concentrations of arsenic from 0.10 to 0.30 mg/l and an installation year after 1981 are classed into this category. This risk zone is distributed from north to south along the middle of the study area. This medium risk zone covers about

UNION GHONA

SPATIAL ARSENIC RISK ZONES

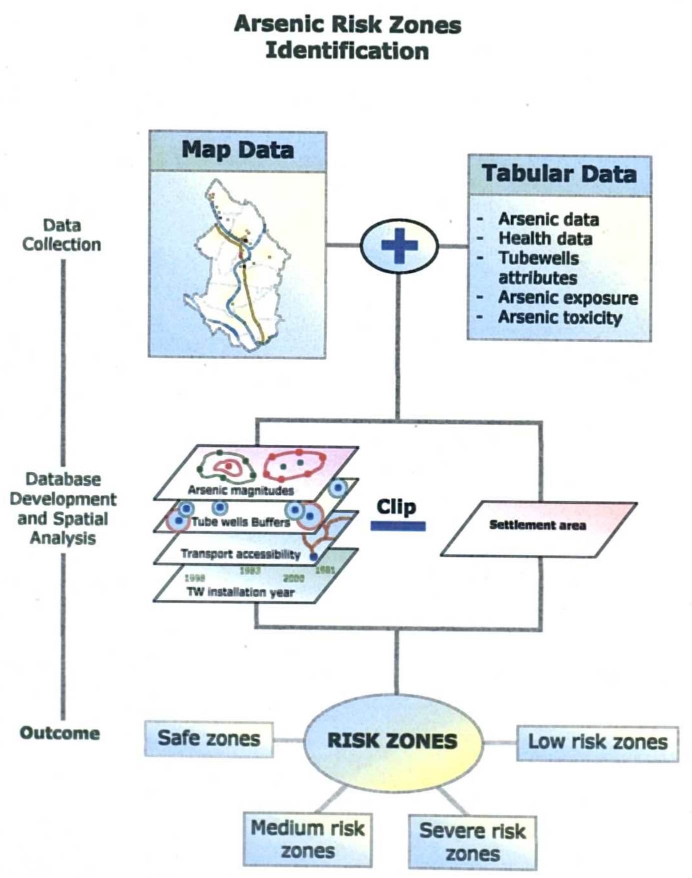
LEGEND

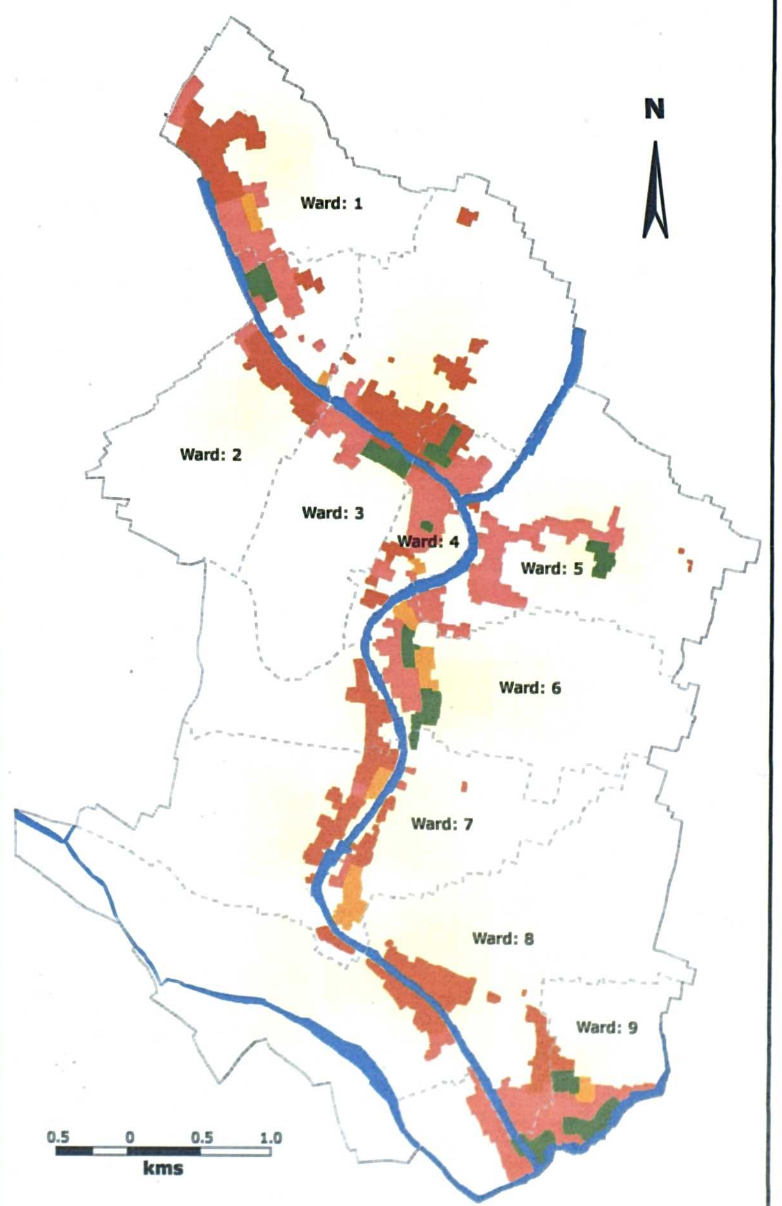
Spatial risk zones
- Safe zones
- Low risk zones
- Medium risk zones
- High risk zones

Main land features
- Agricultural land
- Rivers/Cannals

Spatial Risk Database

Risk zones	Area (ha.) (%)	Population Covered (%)
Safe	7.70 (3.17%)	1760 (16%)
Low	10.16 (4.18%)	1375 (12.50%)
Medium	96.33 (39.64%)	3163 (28.75%)
High	128.80 (53.0%)	4703 (42.75%)





Prepared by: M. Manzurul Hassan

Figure 4.21

39.64% (96.33 hectares) of the total settlement area. About 28.75% (3163) of the total population collect water from the 200 tubewells in this category. The author did find 2 arsenic affected patients in this category. Both are in the primary stage of arsenicosis symptoms.

(d) **High risk zone.** Areas in which arsenic concentrations range from 0.30 mg/l to 0.60 mg/l and in which the tubewells date from between 1950 and 1996 are classed as high risk zones. About 53% (129.00 hectares) of the total settlement area covers this category. The zones are mainly located in the west and northeast part of the study area. About 42.75% (4703) of the population use severely contaminated water from 126 tubewells located in the high risk zone. The author found 5 people to be arsenicosis patients.

4.7 CONCLUDING REMARKS

The function and utilities of GIS provided analytical information for decision-making and planning in the context of spatial arsenic magnitudes. In this chapter an attempt has been made to promote a spatial risk zoning for the study area using GIS techniques. Apart from this, statistical operations, mainly GLMs, were adopted for analysing the association between arsenic and other parameters. This study has identified the spatial magnitudes of arsenic (Figures 4.6 and 4.7), relationships between arsenic concentrations and aquifer depths (Figure 4.10), association between arsenic and time (Figure 4.15), impact of arsenic on health with risk pattern and characterisation (Figures 4.17, 4.18 and 4.19), and the spatial risk zoning (Figure 4.21).

From the overall discussion, it may be noted that the methodological approaches adopted in this chapter have been justified. This study examined the capability and functionality of GIS in identifying the spatial arsenic risk zoning in the light of the existing micro level arsenic data and other tubewell attributes.

Geostatistical approaches in terms of the IDW, RBF and Ordinary Kriging interpolation methods were used for spatial interpolation. The GIS OVERLAY operations and BUFFER techniques were also employed. GIS (ArcGIS) in this study has been demonstrated to be a valuable tool to handle a wide range of sectoral data bases in a meaningful form. In addition, the GLMs have also been established as a useful technique for analysing the quantitative data for this research.

In reviewing the literature, we have focussed on the pattern of arsenic magnitudes in the form of safe and contaminated tubewells, rather than especially proliferated spatial magnitudes. Arsenic is distributed everywhere in the study area, but with different degrees of magnitude. The pattern of spatial arsenic magnitudes shows the topographic features account for its spatial variation. Most of the literature shows that the maximum concentrations of arsenic are at depth between 20 and 45 metres, but the author in this study found dissimilar relationships between aquifer levels and arsenic concentrations. Moreover, deep tubewells were found to be contaminated, but with low levels of arsenic concentrations.

The relations between aquifer depths and arsenic concentrations in different administrative wards suggest that geology is the major factor controlling the spatially dependent component of the variation of arsenic concentrations at different aquifer levels. This has also been suggested from the spatial arsenic variation in the same and certain aquifer depth that in some parts of the study area, factors other than geology can account for a substantial proportion of the spatial variation in arsenic concentrations. The time factor is likely to result in a spatially correlated component of variation since people are continuing to install more tubewells and tapping more water from the aquifers.

It is found from the various published sources that arsenic, in recent times, in Bangladesh and West Bengal (India) is considered to be a 'natural calamity' because of its toxicity. In view of the merits and demerits of the methodologies adopted for this study, it can be said that these approaches would be helpful in analysis of spatial arsenic poisoning in the arsenic research of Bangladesh as well as West Bengal, India.

The statistical and spatial databases were employed for the chapter. The statistical and spatial analyses reflect the overall situation of arsenic magnitudes and its effects on health, but the databases do not reproduce the inherent health problems of the patients. The next chapter will describe the people's perceptions about the health impact of arsenic and how they manage their health problems. The methodology for the next chapter will focus mainly on the qualitative database in exploring the health hazard of the study area.

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CHAPTER V

ARSENIC EXPOSURE and HEALTH HAZARDS: DIFFERENT PEOPLE DIFFERENT VOICES

CHAPTER – V

ARSENIC EXPOSURE and HEALTH HAZARDS: DIFFERENT PEOPLE DIFFERENT VOICES

Understanding people's perceptions regarding the arsenic impact on health is an important objective of this thesis. This chapter seeks to explore people's perceptions about the terminological issues of arsenic, risk, and health hazard and what has changed in the last few years regarding the impact of arsenic since groundwater arsenic contamination was first identified in Bangladesh. How do local people manage their health situations caused by chronic arsenic ingestion? The answers to this question will reveal the health conditions of arsenic-affected patients. This chapter investigates the perceptions of arsenic-affected people and explores patients' (those suffering from arsenicosis) ideas about the management of arsenic toxicity (i.e. what local arsenic-affected people think and do). It examines their own understandings of arsenic, arsenicosis and related diseases, risk, and difficulties they are experiencing, their survival strategies in terms of coping and adaptation strategies as well as the solutions they envisage to their problems. The chapter dwells on the voices of rural patients who are the best judges of their experiences and whose views on the solutions to their problems are also important.

The materials presented are aimed at providing a qualitative analytical description of arsenic impact on health with the issues of survival strategies in mind. The chapter is divided into seven sections. The first section presents the qualitative enquiries in eliciting people's understandings about the impact of arsenic on health. Section 5.2 seeks to explore people's understanding of terminological issues related to arsenic, risk and health hazards. Section 5.3 presents people's perceptions about arsenicosis symptoms and problems the patients are experiencing. Section 5.4 discloses the survival strategies that arsenic-affected patients and unaffected people are adopting and are planning to adopt. Section 5.5 describes patient-doctor conflicts regarding treatment strategies and section 5.6 describes people's ideas about how arsenic leads to ill health (health hazards) in their lives. Finally, section 5.7 makes some concluding remarks on the overall analysis.

5.1 INVESTIGATING PEOPLE'S UNDERSTANDINGS: QUALITATIVE INQUIRY

Qualitative inquiry is the interpretive approach for exploratory study (Winters, 1997). The previous chapter (Chapter IV) mainly focussed on spatial and statistical aspects of arsenic magnitudes, exposure assessment and risk characterisation. This chapter employs mainly qualitative methods to measure people's understandings of arsenic, its toxic impact on health and their own survival strategies. Arsenic-affected patients are asked to determine their 'own priorities' (Korboe, 1998) in measuring arsenic toxicity on health.

Qualitative data are the source of well-grounded, rich description and explanations of processes in identifiable local contexts (Miles and Huberman, 1994). Qualitative methods rely on multiple information sources and emphasise diversity of techniques. The methods underline the complexity of human life - how people understand their worlds and how they create and share the meanings about their lives (Kyei, 2000). They thereby elicit in-depth answers about culture, meanings, processes and problems (Rubin and Rubin, 1995). The qualitative methods in this research bring forth in-depth realities about arsenic toxicity on human health and people's coping strategies concerning arsenic poisoning.

Qualitative research methods are appropriate to use when describing a phenomenon about which little is known (Morse, 1992). The methods are particularly suited when describing a phenomenon from emic (individual) perspectives (Ford-Gilboe *et al*, 1995; Morse and Field, 1995; and Polit and Hungler, 1991). Thus, use of qualitative methods is central to this study in order to elicit perspectives about how people make sense of their lives, about experiences of arsenic poisoning and the survival strategies that they are adopting.

The participatory approach, in this thesis, has supported an epistemology of the health situation that relies on local understandings and perceptions. A central objective of the participatory approach is to ensure that the voices of local people or different groups figure prominently in the dialogue (Shaffer, 1996). Local ordinary people are frequently regarded as 'inactive, tradition-bound, unimportant and ignorant' (Kyei, 2000), although in reality they can make a considerable contribution to the development of arsenic-related policy. The in-depth interviews and focus-group discussions were used to define different people's own understandings about the impact of arsenic on human health and subsequent survival strategies. These involved sufferers, non-sufferers and groups containing different occupations.

The study was designed to bring out the details from the viewpoint of the participants using multiple sources of data (Figure 5.1). Triangulation strategies were adopted to ensure accuracy (Tellis, 1997) and alternative explanations (Stake, 1995) with data, theories, and even methodologies (Snow and Anderson, 1991) in confirming the validity of the processes by using multiple sources of data (Yin, 1984). Multiple methods of data collection can enhance understanding of the phenomena under study (Breitmayer *et al*, 1993 and Ford-Gilboe *et al*, 1995). A wide variety of qualitative methods in terms of PRA, participant observation, open structured in-depth interviews, and focus-group discussions were carried out in this regard. Some twenty-three in-depth interviews and five focus-group discussions were accomplished in this study.

The in-depth interviews, focus-group discussions, and informal conversation and discussions with different people (i.e. tubewell holders, arsenicosis patients and unaffected people in different occupations) provided insight into how people think about arsenic, arsenicosis and related diseases, health hazard, environmental risk etc. All interviews and group discussions were conducted with an audio recorder.

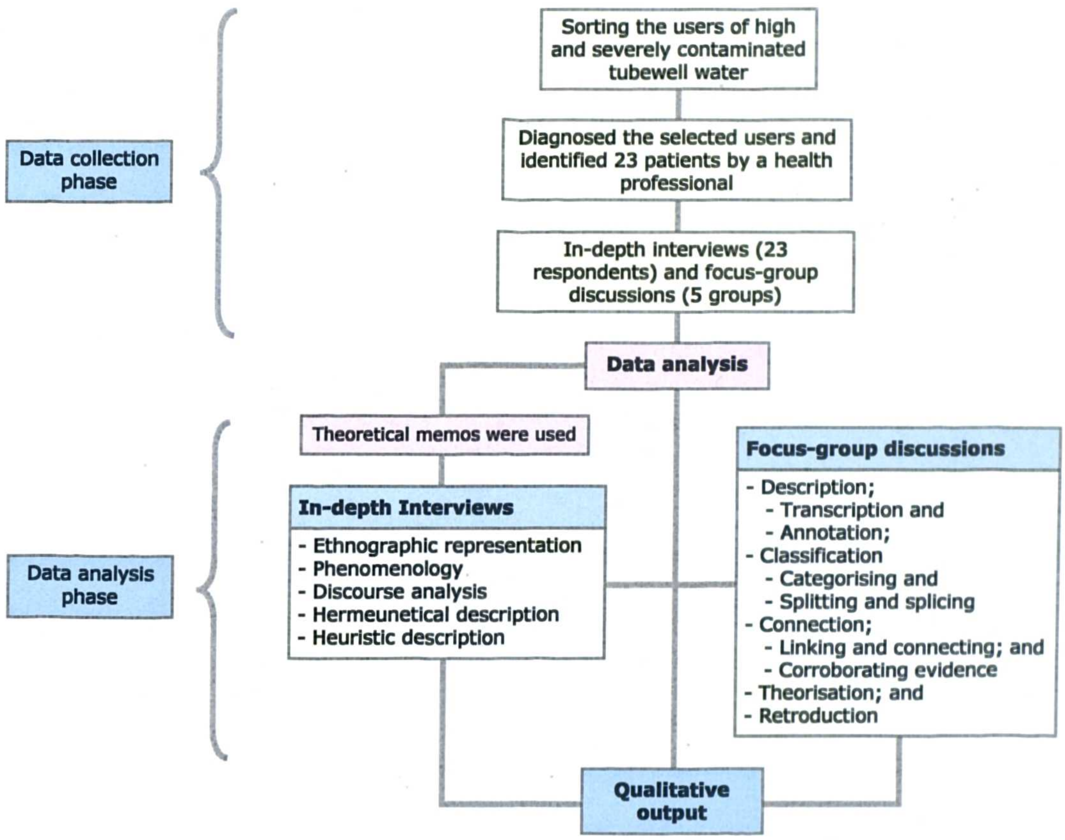

Figure 5.1: Flow chart for data collection and analysis.

The selected five focus-groups theoretically cover the range of very poor to rich people, illiterate to literate people, landless farmers to land holding farmers, local NGO officials to different local government officials, local social activists to local political leaders, and finally local elected administrators. Discussions were recorded and photographs were also taken of the focus-group participants as well of the in-depth interviewees.

Qualitative modes of analysis have mainly been concerned with textual analysis and the resulting data can be analysed from multiple perspectives using different analytical modes (Miles and Huberman, 1994; Silverman, 1993; and Wolcott, 1994). The 'thick description' (Geertz, 1973) mode was used to consider the data without interpretation and abstraction; 'ethnographic representation' was used to create a 'rich descriptive narrative' (Strauss and Corbin, 1998) and a vivid presentation of new understandings; and 'phenomenology' and 'discourse analysis' were used to build new understandings and theory using high levels of interpretation and abstraction (Bunne, 1999 and Strauss and Corbin, 1998).

Theoretical memos (Glaser, 1978; Maxwell, 1996; Pandit, 1996; and Miles and Huberman, 1994) were used during data coding for keeping track of all categories, properties, and generative questions that evolve from the analytical process. The theoretical memos contain coding products, summary notes, and concepts that are potentially sensitive in possible story lines. The collected text data from in-depth interviews and focus-group discussions were transcribed and analysed using the following techniques (Winters, 1997):

(a) the transcribed interview data were divided into units designated by the subject matter being described;

(b) individual units from each interview were coded using topical codes;

(c) the codes were grouped into clusters of similar topics and recoded using interpretive codes; and

(d) the interpretive codes were grouped to reflect the themes.

5.2 TERMINOLOGICAL ISSUES: PEOPLE'S UNDERSTANDINGS

5.2.1 Concept and delineation of arsenic

What do the local people know about arsenic? The respondents of in-depth interviews and the different focus-group participants identified different meanings of arsenic (Box 5.1 and Table 5.1). The arsenic issue is new in the study area and a remarkable number of people do not know anything about it. People's perceptions of arsenic have been summarised in meaningful forms following data abstraction and high levels of data interpretation (Bunne, 1999; Rich and Ginsburg, 1999; and Strauss and Corbin, 1998).

BOX 5.1
Concept and nature of arsenic
(In-depth Interviews)

Salam	:	Arsenic is a 'poison' (*bish*).
Kalam	:	It is 'a kind of poison' (*eak prokarer bish*). If people take this poison from tubewell water they can get 'sick' (*doorbell*).
Aslam	:	It is a 'disease' (*roag*).
Jhilam	:	It is a 'dangerous disease' (*maaraattak roag*). People may die if they are affected with arsenic.
Golam	:	Arsenic means that you could get 'black spots' (*zengoo*) on your palms and soles.
Helal	:	Palms and soles may become 'rough' (*khas-khase*), 'hard' (*shokto*) and 'thickened' (*mota*).
Belal	:	You can also get 'sores' (*ghaa*), 'blisters' (*foskaa*) and 'swelling spots' (*goottee*) on your body.
Dulal	:	'Gangrene' (*chamra pachan roag*) and 'cancer' (*canser*) can affect you if you continuously drink arsenic for a long period.
Kamal	:	No medicine has yet been invented for arsenic diseases.
Jamal	:	People may die without getting any treatment if they are affected with arsenic seriously.
Tamal	:	Safe drinking water is the only medicine for arsenic-related diseases.

Data source: Field survey, 2001.
Remarks of respondents from in-depth interviews (names have been changed).

(a) **Poison:** The majority of the focus-group participants and some respondents defined arsenic as 'a kind of poison' (*eak prokarer bish*). They thought that arsenic is mainly concentrated in tubewell water, while some assumed that a few tubewells contain arsenic poison and some not. They also supposed that water with this poison can be the cause of harm to human health, and that people can even die if they take this poison continuously.

(b) **Germ:** Some participants considered arsenic as a 'germ' (*jibaanu*) contained in tubewell water. They thought that people could be

Table 5.1.
People's perceptions of the concept and nature of arsenic
(Multiple responses)

Concept of arsenic	Respondents (Frequency)						
	In-depth interviewees	Focus-groups*					Total
		FG-1	FG-2	FG-3	FG-4	FG-5	
'Poison' (*bish*) and 'one kind of poison' (*eak prokarer bish*).	8 (7.41)	3 (2.78)	7 (6.48)	5 (4.63)	6 (5.56)	4 (3.70)	**33** (27.97)
'Germ' (*jubaanu*).	-	1 (0.93)	4 (3.70)	1 (0.93)	3 (2.78)	1 (0.93)	**10** (8.47)
'Iron' (*eiron*).	13 (12.04)	6 (5.56)	-	-	1 (0.93)	1 (0.93)	**21** (17.80)
'Disease' (*roag*).	9 (8.33)	3 (2.78)	5 (4.63)	4 (3.70)	3 (2.78)	3 (2.78)	**27** (22.88)
'Water borne diseases' (*panibahito roag*) like cholera and diarrhoea.	2 (1.85)	2 (1.85)	1 (0.93)	2 (1.85)	7 (6.48)	3 (2.78)	**17** (14.41)
Total responses:	**32** (29.63)	**15** (13.89)	**17** (15.74)	**12** (11.11)	**20** (18.52)	**12** (11.11)	**108**

Data source: Field survey, 2001 (In-depth interviews and focus-group discussions).
Figures in the parentheses indicate the percent of respondents/participants for each symptom.
* Focus groups have been denoted as five categories i.e. FG-1 (Farmers); FG-2 (Teachers); FG-3 (NGO and Govt. officials); FG-4 (Political leaders and social activists); and FG-5 (Elected administrators).

affected with different diseases, mainly indigestion, if they drink tubewell water containing this germ. Some thought that this water-borne germ entered Bangladesh from Kolkata (the capital of West Bengal, India) during the recent flood (the study area was flooded in November 2000 for the first time since 1954). This germ is felt to cause many skin diseases and before the flood, there were no skin problems. Some people thought that going bare-foot and working in the fields contributed to contracting the skin disease, where feet swell up slowly and show skin discolouration.

(c) **Iron:** Some respondents and participants assumed that arsenic means 'iron' (*eiron*) and had never heard anything specific about arsenic. It should be noted that iron concentrations in tubewells are as high as arsenic in the study area (the iron data were also analysed). When asked about arsenic concentrations in tubewell water, some respondents confused arsenic with iron. Many people, mainly tubewell holders did not know in detail what arsenic is, but some had a little knowledge of arsenic and its impact. When telling local people that arsenic is mainly concentrated in tubewell water, they replied, ". . . Oh, yes, we know about arsenic, it is red in colour" which refers to iron but not to arsenic.

(d) **Disease:** Some respondents recognised arsenic as 'a type of dangerous disease' (*eak dhoroner maaraattak roag*) and some focus-group participants considered it to be a 'disease' (*roag*) of different symptoms. Some respondents considered arsenic-related diseases to be similar to eczema (*eakzima*). The focus-group participants took into account that arsenic symptoms could vary from skin lesions (sores - *ghaa*) to gangrene (*chamra pachan roag*) and finally to skin cancers (*canser*). A very few participants confused arsenicosis with leprosy (*koosto roag*). They also thought that arsenic-related diseases are contagious (*choaachea*). Some respondents and participants assume that the 'arsenic disease' is a contaminant in tubewell water.

(e) **Water-borne diseases:** Some focus-group participants considered arsenic as 'water-borne disease' (*panibahito roag*). They considered that cholera (*kolera*) and diarrhoea (*daiiria*) are the resultant effect of the chronic impact of arsenic.

5.2.2 Perceptions and configuration of 'risk' and 'health hazard'

Residents of the study area were faced with serious flood damage a few weeks prior to the start of the field survey. Many had lost their homes, cattle and crops. When I started to collect the water samples from each tubewell, some people asked me whether they would get any aid. I attempted tactfully to manage these situations to uncover people's perceptions about risk and health hazards (details in Chapter III). Most people's opinions about risk focussed on the 'chance of facing flood damage'. When asked about arsenic risk, some people responded angrily, ". . . forget your arsenic, the floods damaged our homes, properties and crops, and we need relief."

There were different conceptions of 'risk' and 'health hazard' raised in both the in-depth interviews and focus-group discussions (Box 5.2 and Table 5.2). People's perceptions about 'risk' and 'health hazards' elicited through PRA, in-depth interviews and focus-group discussions have been summarised here (Box 5.2 and Table 5.2) following the hermeneutical (Myers, 1997 and Ratcliff, 1999), narrative (Atkinson, 1998; Bochner, 1997; Cortazzi, 1999; and Reisman, 1993), discourse (Crush, 1991; Ratcliff, 1999; and Rich and Ginsburg, 1999), and ethnographic (Fielding, 1993; Hammersley and Atkinson, 1995; Harvey, 1990; and Hodgson, 2000) modes of analysis as well as grounded theory approach (Glaser and Strauss, 1967).

(a) **Possibility and/or Chance:** The common perception of 'risk' to many respondents and focus-group participants focuses mainly around the 'possibility of adverse health effects' (*shareerik* *doordashar shambhabona*); while, some respondents and participants articulated risk as the 'chance of getting diseases' (*roag-balai hobaar shambhabona*). Opinions are mainly confined to the idea that if people ingest arsenic-contaminated tubewell water, there is a possibility of getting diseases. They also defined 'health hazard' in this way that if people suffer health damage from an 'unexpected' situation, i.e. due to severe arsenic poisoning. Some focus-group participants reported, ". . . we don't know anything about what you are saying, but we can say, we are suffering from many types of problems, yet we think there is no risk (*jhuki*) in our life." One participant said in this regard, ". . . when I will come to know I'm going to die, then I think my life is at the risk."

BOX 5.2
Concept and nature of risk and health hazard
(In-depth Interviews)

Kalam	:	Risk is a 'chance' (*shambhabona*) of getting diseases (*roag-balai*).
Jhilam	:	I don't know, but I think, 'arsenic is risky'.
Golam	:	It is the 'possibility of death' (*mtittoor shambhabona*). If people intake arsenic, they could die.
Dulal	:	Risk is the 'approaching of hazard' (*beepod ghonea asha*). If there is any 'possibility of danger' (*beepoder shambhabona*), then it can be said that people of that area are at risk.
Belal	:	If people drink 'arsenic contaminated water' (*arsenic-wala pani*), they will be at risk of a 'health hazard' (*shareerik beepod*).
Shahin	:	I don't know accurately, but I can tell you that if there is any 'possibility of death' (*mtittoor shambhabona*), then we can say we are at risk.
Tuhin	:	I don't know anything about health hazards, but I think if people die mainly due to the 'health problems' (*shareerik karon*), then it could be called a 'health hazard' (*shareerik beepod*).

Data source: Field survey, 2001.
Remarks of respondents from in-depth interviews (names have been changed).

(b) **Death:** Some respondents and focus-group participants recognised the meaning of risk as the 'possibility of death' (*mtittoor shambhabona*). If arsenic can take people's lives then it can be recognised that 'arsenic is risky'.

Table 5.2.
People's perceptions of risk and health hazard
(Multiple responses)

Concept of risk and social hazard	Respondents (Frequency)						
	In-depth interviewees	Focus-groups*					Total
		FG-1	FG-2	FG-3	FG-4	FG-5	
Risk:							
'Chance of getting diseases or any harm' (*roag-balai hobar shambhabona* or *khoteer shambhabona*).	2 (1.59)	4 (3.17)	6 (4.76)	3 (2.38)	5 (3.97)	-	**20** (15.87)
'Possibility of death' (*mtittuur shambhabona*).	6 (4.76)	8 (6.35)	3 (2.38)	2 (1.59)	3 (2.38)	4 (3.17)	**26** (20.63)
Risk of getting 'health hazard' (*shareerik beepod*) and 'approaching of hazard' (*beepod ghonea asha*).	5 (3.97)	1 (0.79)	4 (3.17)	3 (2.38)	4 (3.17)	2 (1.59)	**19** (15.08)
'Cause of danger' (*beepoder karon*).	3 (2.38)	-	2 (1.59)	1 (0.79)	-	1 (0.79)	**7** (5.56)
Health hazard:							
'Anything dangerous' (*beepodjanak kono kichu*) to human health.	-	2 (1.59)	5 (3.97)	2 (1.59)	3 (2.38)	1 (0.79)	**13** (10.32)
'Health damage' (*shareerik khotee*) from any source.	1 (0.79)	1 (0.79)	3 (2.38)	-	2 (1.59)	3 (2.38)	**10** (7.94)
'Symptoms of health problems' (*shastho kharaper bhibhinno laskhon*) caused by arsenic.	2 (1.59)	4 (3.17)	6 (4.76)	5 (3.97)	8 (6.35)	6 (4.76)	**31** (24.60)
Total responses:	**19** (15.08)	**20** (15.87)	**29** (23.02)	**16** (12.70)	**25** (19.84)	**17** (13.49)	**126**

Data source: Field survey, 2001 (In-depth interviews and focus-group discussions).
Figures in the parentheses indicate the percent of respondents/participants for each symptom.
* Focus groups have been denoted as five categories i.e. FG-1 (Farmers); FG-2 (Teachers); FG-3 (NGO and Govt. officials); FG-4 (Political leaders and social activists); and FG-5 (Elected administrators).

(c) **Hazard:** Some respondents defined risk as the 'approach of a hazard' (*beepod ghonea asha*). If there is any possibility of danger, then it can be said that people of that area are at risk. When asked about risk from arsenic, some respondents said that they did not know, but others said that if people drink 'arsenic contaminated water' (*arsenic-wala pani*), there will be a 'health hazard' (*shareerik beepod*). Many respondents of in-depth interviews were unfamiliar about 'risk' and 'health hazard', but, some respondents had very straightforward views. Some thought, ". . . if we see people are going to die, we can consider their situation as at risk". One respondent said with a strong voice, "I don't know accurately, but I can tell you that if there is any possibility of death, then we can say we are at risk." When asked about health hazards, they said, ". . . that's all, people can die mainly due to health problems."

(d) **Cause of danger:** Some participants in different focus-groups understood the term 'risk' to mean any 'cause of danger' (*beepoder karon*). It is their opinion that if people can face any risky work then it will be a cause of danger. In defining 'health hazards' they said, "if anything dangerous happened to human health, then it can be called health hazard". Such perceptions of 'risk' and 'health hazard' are mainly confined to the 'danger to health' (*shareerik beepod*) if people receive high doses of arsenic from tubewell water. Some participants assumed that if people ingest dangerous levels of arsenic, they will be at risk of getting the symptoms of gangrene and cancers; and it will be called health hazard when people display symptoms on their body.

5.3 ARSENIC EXPOSURE and HEALTH EFFECTS: PEOPLE'S VOICES

What do arsenic-affected people as well as the unaffected people think about arsenic-related diseases? Do they know about the toxicity of chronic arsenic ingestion? The answers to these questions will help us to describe local people's health conditions. First, I had to select respondents from the arsenic-affected patients. In addition, I selected unaffected people for in-depth interviews and focus-group discussions about their own understandings of the toxicity of arsenic and its impacts on human health, as well as the kind of panic caused by arsenic. In seeking to explore perceptions about health situations of the arsenic-affected people, I examined their own understandings of the problems and difficulties they are experiencing from their disease. Ethnographic representation, discourse analysis, thick description, phenomenology and narrative analysis were employed in examining the textual data.

5.3.1 Voices from arsenic affected patients

All arsenic-affected patients were interviewed about the historical trend of arsenicosis and about their symptoms. No one in the study area knew of arsenicosis before 1998 and they did not realise at first that their tubewells could be contaminated with arsenic.

Symptom recognition and health conditions: This section seeks to explore the sequential development pattern of arsenicosis symptoms and the meanings that patients attached to them. From the ethnographic representation, it seems that during the early stages of illness, people ignore the symptoms and continue with their regular work. Since arsenic poisoning is new, participants denied the severity of the symptoms due to their unfamiliarity. In addition, the 'thick description' (Geertz, 1973) mode of analysis uncovers the real picture about arsenic awareness of the rural people without interpretation and abstraction. This mode of analysis reveals the complacency of one patient that: ". . . almost everybody in this village got black spots (*zengoo*) on their palms and soles, it is not a disease, if you take rest for few days or if you do not toil in the paddy field, then you will come round and you do not need any medical treatment."

There is a lack of awareness surrounding health issues and some of the recent health problems caused by arsenic toxicity are of a low priority to many rural poor people. The health problems are mainly concentrated among poor rural people who are not health conscious and are illiterate. They suffer from both malnutrition and undernutrition usually and most of them are unaware of the seriousness of their illness. They are gradually becoming weaker, losing weight and regularly complain about various sicknesses including a vomiting tendency, headaches, skin irritation and so on. They see issues surrounding health and illness as 'non-threatening' (Gibbon, 2000). Patients try to ignore their health problems and are not so worried about them, since poverty has captivated them. Day to day survival is their main concern, not arsenic, although some patients do know about the impact of arsenic toxicity. When I told them about the chronic impact of arsenic (i.e. if people continuously ingest arsenic for 20-25 years, they could get cancer), one middle-aged (about 45 years) respondent replied:

> ". . . . Oh, cancer! 20 years later, I don't know whether I'll be alive in the next 20 years or not. I'm not worried about arsenic. I need food. If I don't go out for work, I will not get any food and my family will die." [In-depth interview, 2001].

A key finding of the study then is that poverty is the main barrier in raising awareness about arsenic. The devastating flood in 2000 in the study area made many families economically disadvantaged. The flood damaged their crops, cattle and property and they are mainly thinking about the mitigation of their economic problems rather than about arsenic poisoning. One respondent in this regard said, ". . . I don't have time to think about arsenic. Floods damaged my home and crops, and I want to rebuild my home."

Arsenicosis patients describe their disease as a '*zengoo*' (black spots) and this is the most common symptom in the study area. Anwar (2001a) has also pointed out that skin lesions caused by arsenic are considered mainly as a skin disease in Bangladesh and that only a few people know about the relationship between arsenic in drinking water and skin lesions. At the primary stage some '*gotta*' or '*goottee*' (swelling spots) develop on palms and soles and there is '*chulkani*' (itching). These '*gotta*' or '*goottee*' turned into '*zengoo*' which develop slowly. Later the skin becomes dark in a spotted form due to the deposition of a black pigment. These spotted black pigments on palms and soles become thickened (*mota*) and hard (*shokto*).

The hermeneutical mode of analysis provides the 'philosophical grounding' (Bleicher, 1980 and Myers, 1997) for understanding people's perceptions of their health status. The statements of a patient seriously affected with arsenicosis are treated with hermeneutics, displaying the 'verbatim quotations' (Baxter and Eyles, 1999) from a range of available interview texts, for instance:

> ". . . . about 6 to 7 years ago, there developed blisters (*foskaa*) on my whole body and there was a lot of itching (*chulkani*). Few months later, these blisters turned into black spots (*zengoo*) on my hands and legs. There were itching and some pains on there. Few years later, these black spots became hard (*shokto*) and rough (*khas-khase*). Now it has turned into sores (*ghaa*)." [In-depth interview, 2001].

Some respondents described their initial symptoms as 'indigestion'. It is noted here that iron is also highly concentrated in the tubewell water and most people suffered indigestion and abdominal problems. One respondent stated here that he is experiencing a 'boring ache in his tummy'. Some respondents referred generally to 'stomach trouble' or 'tummy-bug'.

Thinking about the disease: Some patients had little idea about arsenicosis, and had not heard about arsenic from any source. They mainly thought that their problems were traditional and they neglected the symptoms due to familiarity with the symptoms of black spots. Most patients thought that their skin lesions become worse during the winter because of the hard soil where they work. Some patients also thought that during the rainy season they got worse because of the mud in the marshy land (*beel*), but not as much as the winter. One patient narrated in this regard that:

> ". . . . During the winter, the situation becomes worse due to the hard soil in the marshy agricultural land (*beel*) where I work. When I don't go to work, I feel a little bit better." [In-depth interview, 2001].

Patients living with chronic arsenicosis work in an inconsistent way i.e. they are irregular due to the lack of work and most patients are engaged in agriculture. Some are very poor and they are the only earning members in their respective families. Therefore, they have to work for food. Participants expressed their aspiration to live, and they thought that if they got arsenic-related diseases, they would have to live with the disease and continue to work to sustain their family.

Health within illness: An attempt has been made here to explore the health conditions of the patients during their illness. The phenomenological approach uncovers the understandings of a patient's health within their sickness through the meanings they 'attach to experience' (Bergum, 1989 and Ratcliff, 1999) i.e. how an individual patient experiences their health problems caused by arsenic ingestion. Through this phenomenological mode of analysis, we can appreciate the patient's experiences about their regular life, i.e. how they manage their regular life during their illness. When people come to know that they are affected with arsenicosis and that no medicines have yet been invented, their attitudes, behaviour etc, change (Box – 5.3).

BOX 5.3
(Biography of an arsenic-affected patient)

Mr. Kalam lives in Bashiapara village at Ward - 2 in Ghona *Union*. He is about 40. He maintains his family life with his wife, son and daughter. He is a landless farmer and a daily labourer. He earns about Taka 40 (£0.50) daily during the *Aman* and the *Rabi* seasons (Wet and winter seasons); while rest of the year (about 5 months) he earns only Taka 25 (£0.30). Mr Kalam is poor. It is very difficult to run a family with Taka 30 (£0.36) daily.

He has been diagnosed by a health professional as an arsenicosis patient at a serious level. He has been suffering the disease for about 7 years. Since he works as a daily labourer at the *Dat-Bhanga Beel* (a marshy-paddy land), he always drinks water from a tubewell located at this *beel* (Tubewell_id: 183). The arsenic concentration of this tubewell is 0.400 mg/l. In addition, he always collects water from the nearby tubewells and arsenic concentrations range here between 0.298 mg/l and 0.436 mg/l.

Before my field survey, he knew nothing about arsenic and its poisoning. He always feels nervous and melancholy for his health condition. He was healthy, but now he is ill and sometimes cannot work. He did not know that he was drinking poisonous water. At the beginning of this disease, there was an itch on his feet and some black spots developed slowly there. These black spots became hard and rough. This type of situation developed on his hands later. The situation is becoming worse and it is difficult to move the fingers easily.

He used to go to physicians. He went there several times. He took medicines as per their prescriptions for 4 to 5 years, and there was no improvement for this disease, but the situation got worse slowly. He told me, ". . . I would continue the medicines, until I can no longer afford. When there is no improvement, what is written in my fate, must happen."

Data source: Field survey, 2001.
Remarks of an arsenic-affected patient (name has been changed).

Patients with a long history of health problems are disheartened about the decline in their health. They are concerned about their declining strength and 'inability to do what they used to perform' (Winters, 1997) since the worsening condition of their palms and the soles of their feet. Some patients reported that their thinking about their illness is changing due to the current arsenic scare. I found from the ethnographic representations that some patients were thinking about arsenic toxicity and that arsenic poisoning is becoming the primary focus of their survival strategy.

Arsenicosis patients find it difficult to do any work with 'black spots' on their palms and soles. Also it is difficult to use their fingers if their palms are affected with sores (*ghaa*). These 'black spots' are painful, especially if they harden. Zaman (2001) points out that arsenicosis patients generally have black warty nodules on their palms and soles and that these can change into cancerous gangrene.

The 'heuristic approach' can present health conditions in the voice of affected patients. A young woman patient affected with arsenicosis narrated that: ". . . I got blisters (*foskkaa*) and swelling spots (*goottee*) on my palms and soles. There is no itching (*chulkani*), but a little bit of pain (*baatha*). When I work and write, I get more '*baatha*' (pain)." The patients thought that they would recover from these skin lesions, but their situation worsened and they are upset at their present health condition. It can be seen from the heuristic approach that patients become worried and may panic about the skin lesions. One patient in this connection seemed depressed:

> ". . . . My feet and hands are becoming harder and sometimes they are as hard as steel (*ishpat*). It is bad looking and I hate to look at my own hands and feet. I'm continuously using ointment (*molom*) and swallowing medicines (*oshud*), but there is no improvement. The situation is getting worse." [In-depth interview, 2001].

Most of the patients know that arsenic is mainly concentrated in tubewell water and that people can die with gangrene or cancer if they ingest substantial amounts of arsenic for a long time. Some have heard about arsenic from radio or television etc, but they took little notice of the information. When they realised that they had been continuously ingesting arsenic contaminated tubewell water and are affected with arsenic-related diseases, only then did they become nervous. The wife of a patient in this regard described her husband who has arsenicosis:

> ". . . . He is always sick and his sickness has been for the last three to four years. When he came to know that he is suffering from arsenic-related disease, he is depressed all the time and he cries everyday since his health condition is getting worse slowly." [In-depth interview, 2001].

Some patients expressed their fearful opinions when they came to know that no cure is available for arsenicosis. One patient made a comment that when he knew that he had arsenicosis, ". . . I'm sure my life is becoming shorter and shorter, and soon I'll not be alive anymore." Some patients have come to know that arsenic poisoning can lead to a 'terminal disease' (*moron baadhi*).

5.3.2 Voices from unaffected people

Some unaffected people were also chosen for in-depth interviews and focus-group discussions in order to get their perspectives about the toxic effects of arsenic. They had obtained their information about arsenic from different sources, such as radio, television, newspapers, leaflets and so on.

The respondents from the in-depth interviews and different focus-group participants are differentiated by occupation, education and income levels. Variations in perception are noticeable both within and between focus-groups with respect to different understandings.

In a general sense, unaffected people's perceptions about arsenic and its toxicity are mainly confined to poison (*bish*), diseases (*roag-balai*), gangrene (*chamra pachan roag*) and cancer (*canser*). Most of the respondents/participants consider arsenic to be poisonous matter, that it is concentrated in tubewell water and that such an unseen poisonous element is dangerous to human health. One female respondent told me in this regard that:

> ". . . . Arsenic is a kind of poison and is existing in the tubewell water everywhere in Bangladesh. It is dangerous and harmful to human health. If people drink this arsenic contaminated water, they will get many diseases." [In-depth interview, 2001].

Some people thought that arsenic is poisonous, and that it affects human health chronically. Long-term exposure to arsenic causes different types of skin lesions like blisters (*foskaa*), sores (*ghaa*), black spots (*zengoo*) etc, on palms and soles. One female respondent said:

> ". . . . Arsenic is a kind of poisonous element that slowly affects human health. It can develop skin lesions and these can be visible 20-25 years later. If anybody is affected with arsenic, s/he gets blisters (*foskaa*) on his/her body, itchy (*chulkani*) and black spots develop on his/her palms." [In-depth interview, 2001].

Some participants in the focus-groups defined arsenic as a dangerous poison (*marayattak bish*); while some considered it as fatal disease (*moron baaedhi*). In a focus-group, people's understandings of the impact of arsenic on human health are mainly confined to the following diagnostic form:

> ". . . . Arsenic is a dangerous poison. It exists in water. People could get many types of diseases if they drink this contaminated water, they might even die. Therefore, arsenic is a terminal disease. Arsenic is so dangerous that it can cause cancer. The recent arsenic problems make the people panic about cancer. People are so responsive that they know that if arsenic once attacks people they will die without getting any treatment." [Focus-group discussion, 2001].

Some respondents were scared of arsenic and get in a panic thinking that if arsenic attacks them, they will die with arsenic related cancers. One female respondent who had training several times from her family-planning office told me about the high probability of health harm from continuous ingestion of arsenic:

> ". . . . Arsenic is a dangerous poison and people may get different types of health problems if they ingest it. It is so dangerous that no medicine has been invented yet for it. People can even die with gangrene or cancer if they ingest large amounts of arsenic for a long time." [In-depth interview, 2001].

Other participants were not frightened. They knew a little bit about arsenic poisoning. One female respondent in this regard suggested that "people are not getting in a panic because they don't know significantly about the effect of arsenic toxicity on human health." In a question concerning awareness about arsenic toxicity, another respondent replied, ". . . yes, I have heard about arsenic, but I don't give any importance to it. I've seen advertisements about arsenic on television, but I ignore them." When I asked him why he ignored them, he replied to me that: "I don't know what arsenic is and I don't know who are the people affected with arsenic-related diseases."

Some people know about arsenic, but they consider the issue unimportant. As in the words of one respondent, ". . . I know this tubewell water is better than others, so I'll drink water of this tubewell, I'll not go to another tubewell for collecting water. I'm still drinking this arsenic contaminated water and I don't feel anything bad." Some people thought that life and death are in the hands of God. Everything will happen with God's wish and nothing will happen against God's wish. Some people strongly believe in God and they do not panic when they know that their tubewells are contaminated with arsenic.

> ". . . . Why panic? As long God will keep me alive, nothing will happen with arsenic, or arsenic will not be a problem if God wants to keep me alive (ho! ho!! ho!!!). Will God give you longer live if you drink arsenic-free water? Or, if God wants to take your life now, you must die if you drink either arsenic-free water or arsenic contaminated water, so, arsenic is not a problem." [In-depth interview, 2001].

In view of the phenomenological approach with high levels of interpretation and abstraction, the concentrated perceptions of some of the participants in one focus-group can be summarised into three main stages of arsenic symptoms. Their perceptions are similar to participants in other groups. Their story with rich textual presentation is that:

> ". . . . Arsenic is a dangerous poison. It has three main symptoms. First, roughness (*khosha-khosha*) can appear on palms; second, this roughness develops into gangrene (*chamra pachan roag*) and finally, people can die with cancer (*canser*). It is not possible to recover from this disease." [Focus-group discussion, 2001].

Some people have come to know something about arsenic toxicity through training by different organisations. Some focus-group participants had updated and accurate concepts about arsenic and its adverse health effects. Their training was supplemented by arsenic advertisements on the radio, and they had read something about arsenic from national newspapers. Their perceptions cover both the non-malignant health effects and the common perceptions of carcinogenic and malignant health effects.

> ". . . . Arsenic is a poison (*bish*) and if we drink this water, there might develop black spots (*zengoo*) on our palms and soles, we might get kidney problems or might get heart attacks, or it can damage our blood cells, or it can develop skin cancer." [Focus-group discussion, 2001].

Most of the people in the study area are very poor and the vast majority of them are not interested in arsenic, especially if there is no arsenic-affected patient in their vicinity. They have been drinking tubewell water continuously for several years or even a couple of decades and still they feel that there is nothing adverse in their health due to arsenic ingestion. Some participants noted that:

> ". . . . Since we don't know anything about arsenic, we can't see any difference between tubewell water and pond water - they are all same to us. When we are in the field, we are always hungry and thirsty and always muddy and soiled, and we drink water from any source located closest to us. We do not have the stamina and time to find arsenic-free safe tubewell for drinking water. We don't think whether this water is contaminated with arsenic or not." [Focus-group discussion, 2001].

In sum, there is a sharp difference between the perceptions of affected people and unaffected people concerning arsenicosis and the impact of arsenic on human health. The differences in people's perceptions are mainly based on their education and economic conditions. Arsenic-affected people's perceptions are based on their own experiences; while the perceptions of unaffected people are similar to the expert-concept.

(a) **Non-carcinogenic effect:** Patients' perceptions regarding the symptoms of arsenic-related diseases are mainly confined to skin lesions i.e. sores (*ghaa*), blisters (*foskaa*), boils (*foraa*), and swelling spots (*gotta or goottee*). In addition, black spots (*zengoo*) on palms and soles, skin roughness (*khas-khase chamra*) and skin hardness (*shokto charra*) on palms and soles are the symptoms perceived by the indigenous patients (Table 5.3). No patients in the study area said anything about gangrene and cancer, they talked about the kinds of health problems they had and the kinds of pain they experienced. In contrast, a considerable number in the focus-group discussions assumed that gangrene is the resultant effect of chronic arsenic ingestion and at a certain stage, gangrene could appear in the body.

Table 5.3.
People's perceptions of arsenic-induced diseases
(Multiple responses)

Arsenicosis symptoms	Respondents (Frequency)						
	In-depth interviewees	Focus-groups*					Total
		FG-1	FG-2	FG-3	FG-4	FG-5	
'Sore' (*ghaa*), 'blister' (*foskaa*), 'boil' (*foraa*), and 'swelling spots' (*gutti*).	6 (3.61)	2 (1.21)	4 (2.41)	2 (1.21)	3 (1.81)	3 (1.81)	**20** (12.05)
'Black spots' (*zengoo*) on body.	3 (1.81)	1 (0.60)	6 (3.61)	3 (1.81)	2 (1.21)	-	**15** (9.04)
'Skin roughness' (*khas-khase chamra*) on palms and soles.	3 (1.81)	-	3 (1.81)	2 (1.21)	1 (0.60)	-	**9** (5.42)
'Leprosy' (*Kushto roag*).	8 (4.82)	3 (1.81)	-	2 (1.21)	2 (1.21)	-	**15** (9.04)
'Cholera' (*Kolera*) and 'diarrhoea' (*Dairia*)	7 (4.22)	5 (3.01)	2 (1.21)	3 (1.81)	6 (3.61)	3 (1.81)	**26** (15.67)
'Gangrene' (*Chamra pachan roag*).	11 (6.63)	3 (1.81)	7 (4.22)	4 (2.41)	5 (3.01)	4 (2.41)	**34** (20.48)
'Cancer' (*canser*).	14 (8.43)	5 (3.01)	8 (4.92)	6 (3.61)	8 (4.92)	6 (3.61)	**47** (28.31)
Total responses:	**52** (31.33)	**19** (11.45)	**30** (18.07)	**22** (13.25)	**27** (16.27)	**16** (9.64)	**166**

Data source: Field survey, 2001 (In-depth interviews and focus-group discussions).
Figures in the parentheses indicate the percent of respondents/participants for each symptom.
* Focus groups have denoted in five categories i.e. FG-1 (Farmers); FG-2 (Teachers); FG-3 (NGO and Govt. officials); FG-4 (Political leaders and social activists); and FG-5 (Elected administrators).

(b) **Carcinogenic effect.** The vast majority of unaffected people focus on the carcinogenic effects. They assume that long-term ingestion of arsenic could lead to a cancer risk. They strongly hold the opinion that cancer is the last symptom of arsenic-related diseases (Table 5.3). They mainly mentioned skin and blood cancers.

No arsenic-affected interviewees for this thesis mentioned heart disease, diabetes, circulatory diseases etc. It is also interesting that some respondents and participants mentioned that no medicines have been invented yet to cure arsenic related diseases. Patients' voices on arsenic issues are mainly their own personal stories; while unaffected people drew on knowledge gained from many diverse sources.

5.4 ARSENIC PANIC and SURVIVAL STRATEGY

How do local people manage their health situation during and after chronic arsenic ingestion? The answer will help to uncover the health conditions of the local patients as well as the survival strategies that they are adopting. The initial response to symptoms of black spots (*zengoo*) was based on what the patients usually did in similar situations. Interventions described by the patients included ignoring the symptoms, resting, and taking medicines. Respondents with black spots described how they manage their illness. Survival strategies adopted can be viewed as (a) coping strategies; and (b) adapting strategies.

5.4.1 Coping strategies: patients' voices

In another context Davies (1996) defined a coping strategy as a temporary response to an immediate crisis. In my work, almost all patients frequently addressed the use of medication. Frequent visits to physicians were thought of as necessary in order to get the situation under control (Winters, 1997). Most of the strategies adopted during the time of difficulties or crisis fall into the category of coping. The affected rural people talked of a combination of coping strategies that they employed during their critical health situations. Respondents to in-depth interviews gave varied opinions about how they managed their health situation caused by chronic arsenic ingestion. Many of the people in the study area are suffering from different types of skin diseases due to the recent flood and arsenic problems are therefore only a subset of their overall health worries.

The first strategy: This strategy considers different medical treatments that patients are adopting. Seriously affected patients usually go to a doctor, but most do not until their health condition is bad. Three types of medical treatments are carried on in the study area; (a) allopathic treatment – most people use this treatment method; (b) homeopathic treatment – the very poor people take this method; and (c) ayurvedic treatment – some poor people use this method for their treatment. It is also interesting that there are many quack doctors in the study area and they are providing medicines for arsenic, although no true cure has yet been found.

The majority of arsenic affected patients use **allopathic** medicines for their treatment as prescribed by allopathic doctors since they think that this treatment is the most rapid and reliable in ensuring recovery. Some arsenic-affected patients with serious symptoms went to several doctors and bought medicines for their diseases, but there was no improvement in their health condition. They were continuing to swallow medicines and were putting ointment on their bodies, especially on their palms and soles. One seriously arsenic-affected patient told me that:

> ". . . . Yes, I went to several doctors several times. I've been taking medicines (*oshud*) and ointments (*molom*) as per their prescriptions for the last five years, but there is no improvement of this disease, and the situation is getting worse slowly." [In-depth interview, 2001].

It has been found from an adjacent area (Kolaroa *Upazila* under Satkhira district) that some people who were suffering from arsenic poisoning, after visiting several local doctors, then went to Kolkata (India) for further treatment, but no improvements were found. A popular newspaper article claims that some arsenic-affected patients are trying to go to India for treatment by selling their property (Bangladesh Sangbad Sangstha: 04/07/2001).

Allopathic treatment is very expensive in Bangladesh terms. Under this system, patients have to pay twice for the treatment: first, for a prescription fee to a doctor, and second to a shop for the medicines prescribed. Some patients have decided not to go to any recognised doctor again. They have taken a decision that when they experience any health problems concerning skin diseases, only then will they buy the medicines as per the prescription they paid to the doctors earlier. A patient in this connection said:

> ". . . . I cannot afford a good doctor. I went to a prominent doctor at Satkhira twice and paid TK300 (£4.00) for the prescription fee. It is too expensive. I don't like to go to him again. When I feel bad, I buy medicines following the prescription I bought earlier and use the medicines. In this way, I manage my health conditions." [In-depth interview, 2001].

Some people believe in **homeopathic** treatment and think that this treatment can lead to a cure, although the medicines work slowly. This is much less expensive than that of the allopathic treatment system and poor people mainly go to the homeopathic doctors for this reason. I spoke to a young woman who had been suffering from arsenicosis for two years. She used to take homeopathic medicines for her disease. In an answer concerning her medical treatment, she said:

> ". . . . Yes, I went to a homeopathic doctor several times. I'm taking medicines continuously as per his prescriptions, but I've never found any improvement of this swelling spots (*goottee*)." [In-depth interview, 2001].

Some people believe in **ayurvedic/herbal** treatment. The medicines under this treatment method are made directly with various plants and there are said to be no side effects. People believe that if they continue with such medicines, it will purify their blood; and in pure blood there will be no diseases. They also think that herbal medicines work better than modern drugs. Chowdhury (2001) has similarly pointed to people's opinions in favour of herbal treatment. I spoke to one patient with arsenicosis who used to go to allopathic doctors. He took a lot of medicines, but found no improvement in his skin diseases. He is now going to an ayurvedic physician for treatment.

> ". . . . I went to several doctors for these black spots (*zengoo*). I went to a doctor (name ommitted) of Kathanda Bazar. I bought tablets (*bori*) and ointments (*molom*) from him for more than a year, but I never felt good. Then I showed my problems to another doctor at Ghona *Hatkhola* for a long time and took a lot of '*puria*' (one dose of homeopathic medicine). Still there was no improvement in my health conditions. Some of my friends advised me to go to an ayurvedic doctor at Satkhira, and accordingly I'm doing so and have already bought bottles of medicines (*oshud*). Still I'm not getting a recovery, but I'm hopeful." [In-depth interview, 2001].

Some people prefer in ayurvedic treatment since it is less costly than that of the allopathic and homeopathic treatments. A patient told me that: ". . . the '*Kabiraji*' (ayurvedic/herbal) treatment is not costly and I could continue this treatment until my sores improve." In a popular article it has been found that some arsenic-affected patients are going to 'village *Kabiraj*' to get rid of arsenic poisoning due to their financial constraints (Bangladesh Sangbad Sangstha: 04/07/2001).

The second strategy: The second coping strategy involves taking treatments from **quack doctors** (*haatooree daaktaar*). Many poor patients go to quack doctors since they have lost their trust in other mainstream doctors because there is no improvement in their health condition. Almost none of the patients I interviewed are happy with the treatment they have received for their diseases in clinics and hospitals and thought that it is a waste of money. Some poor patients decided instead to show their diseases to a quack doctor because of the very small amount of prescription and medicine fees. A poor patient in this regard narrated that:

> ". . . . I went to a doctor several times, but I've stopped going there due to financial constraints and I've never felt any improvement of my skin problems there. This doctor told me to take medicines (*oshud*) for a long time. How can I pay his big charge? I'm poor and I can't afford to continue the prescribed medicines for a long time. I used to take a lot of ointments (*molom*), but I never felt better. I've decided to show my problems to a quack doctor (*haatooree daaktaar*) who visits my home every week. He takes a very small amount of money for the medicines." [In-depth interview, 2001].

Anwar (2001a) noted that most arsenic-affected people take treatments from quacks. It was found during the field survey that most patients did not care about their skin problems. They think that their swelling spots (*goottee*) will recover soon. Hence, they do not go to any doctor for treatment.

The third strategy: The third strategy covers the rural primary health care systems. The use of **warm mustard oil** on the body is part of this strategy. At the initial stage of their skin diseases people rub their body a small piece of garlic soaked with warm mustard oil. Patients, mostly poor people, rub their palms and soles with a little warm mustard oil. Later if their health worsens, some then decide to go to a doctor for treatment. One female patient explained:

> ". . . . I used to rub my palms and soles with mustard oil with garlic when I first got swelling spots (*goottee*). I've been following this treatment for the last two years. When I found that there was no improvement in my skin problems, then I went to a doctor for better treatment, but still, I didn't get better." [In-depth interview, 2001].

The fourth strategy: The fourth strategy is to use **traditional** systems of treatment. These include wearing **amulets** (*taabiz*) on the arms or waist, rubbing **charmed oil** (*tel pora* – charmed by incantation) and taking **charmed water** (*pani pora*) on the wound. Some rural poor people believe in these traditional treatment systems, but others don't. A patient who had been suffering from arsenicosis for about seven years was sceptical:

> ". . . . No, I don't believe it. It is meaningless to me to wear any amulet (*taabiz*) on my arm or on my waist. It is fake. How does an amulet work where the medicine does not work in this disease? What benefit will I get from an amulet?" [In-depth interview, 2001].

Another female patient was more trusting: ". . . when doctors fail, then amulets work well." When I asked her about her health after wearing an amulet on her arm (do you feel better now?), she replied, "I hope I will come round within a very short period of time. I've a trust in it." Some respondents said that they can forget their illness when they keep themselves busy in their work.

5.4.2 Adapting strategies: peoples' voices

By an 'adapting strategy', I mean the long-term and permanent attitudes of the local arsenicosis patients in solving their health problems. The vast majority of people in the study area do not have any idea about arsenic and its toxicity, but a few patients are seriously misinformed. When patients have come to know that almost all the tubewells in Ghona are contaminated with arsenic and that they have got the disease, some of them pointed out a combination of adapting strategies for the long-run. Apart from this, many unaffected people are scared of arsenic and they think that if arsenic once attacks them, no medicines can cure them, and they have therefore decided to adopt strategies to prevent arsenic poisoning.

Continuation of medicines: The common perception of some patients is that they will continue to take medicines until they recover. It is an expensive adaptation strategy to continue medicines for a long time for some patients, but they think that this medicine will provide them with stamina in protecting them from gangrene and cancer, but others disagree. When there is no alternative, they think that it is better to continue the medicine whether they recover from arsenicosis or not. In a question concerning the effectiveness of medicines in the arsenic issue, one patient replied that:

> ". . . . I've nothing to do. I would like to continue the medicines, as long as I can afford. If there is no improvement, it is wrriten in my fate, and it will happen." [in-depth interview, 2001].

Collection of arsenic-free water: Some patients have decided to collect arsenic-free water from different deep tubewells close to them. When they have come to know that arsenic-free water is the only preventive measure for arsenic toxicity and that it can recover their health problems, then they make a decision to collect arsenic-free water from safe tubewells. A seriously arsenic-affected patient told me anxiously that:

> ". . . . Are you sure that arsenic-free water can help me (in a high tone)? Why didn't you tell me this at the beginning? I thought that I'm going to die. I will go to the Ghona *Hatkhola* or to the deep tubewell of Jamaluddin for arsenic-free water. I've come to know that these two deep tubewells are arsenic-free." [In-depth interview, 2001].

People of the study area have already developed a habit of drinking tubewell water and at present they are not interested in using pond water again for drinking and cooking. Most respondents and participants were keen on installing deep tubewells to access arsenic-free water. They already knew that deep tubewells are the only source of arsenic-free water. One respondent in this regard noted that:

> ". . . . I have come to know that only arsenic-free water is the preventive measure for arsenic toxicity. Installing 52-piped deep tubewells is the only way to get arsenic-free water. People want to drink arsenic-free water from deep tubewells to prevent arsenic poisoning. I don't know what are the alternative options in this regard. People will prefer deep tubewells to other options." [In-depth interview, 2001].

Filtering pond and tubewell water: This adapting strategy can be applied to areas having no arsenic-free tubewells. People of wards - 1, 2 and 7 have no arsenic-free tubewell water available in their areas, and it is a long distance for people of these areas to collect water from the nearest deep tubewell to them. Some patients in these areas have taken the initiative in getting safe and arsenic-free water by filtering pond water and they have been instrumental in arranging for the use of a manufactured filtering machine. Others use a traditional filtering system (locally known as *tin-Kolshi* method). In this method, at the bottom of the upper and the middle jars there is a small fissure. The middle jar is of charcoal and sawdust. The water from the upper jar drips down to the middle jar and finally to the bottom jar after being purified in the middle jar. One patient gave his opinion in favour of the traditional filtering system that:

> ". . . . Arsenic is a dangerous disease and it is making me ill. If arsenic-free water makes me well, I'll find this water through filtering. I'll make it on my own. I don't know whether this will make the tubewell water arsenic-free or not, but I knew it would make the pond water pathogen-free. If the system works effectively, I'll use it for the rest of my life." [In-depth interview, 2001].

Some respondents and participants have heard that arsenic is not removed from water by filters. They have also come to know that arsenic is not concentrated in pond water and accordingly they decided to filter the pond water instead. People of the middle and upper societal classes are mainly interested in adapting the filtering measures to purify pond water to prevent arsenic toxicity.

"... When I heard that my tubewell is contaminated with arsenic, I bought a filter mechine for purifying pond water. I hadn't use it before, but I have to adopt this measure for our health and safety and I'll continue this measure for rest of my life." [In-depth interview, 2001].

Boiling drinking water: Another adapting strategy is boiling drinking water. This is the traditional preventative against cholera and diarrhoea. A few years ago, before the availability of tubewell water, rural people used to boil water for drinking and cooking. Most people think that they don't want or need to boil water. Some patients boil their drinking water if there is no alternative means of preventing arsenic contamination. However, there are financial constraints. A poor patient in this regard noted:

"... I earn only TK25.00 (£0.32) daily. How can I boil the pond water for my drinking and cooking purposes? Who will provide me fuel wood (*kaath*) for boiling the water? I don't have enough money to buy fuel wood." [In-depth interview, 2001].

It has been found from the study that poor patients neither boil drinking water nor filter pond water. Their main adapting strategy is to collect arsenic-free water from the nearest deep tubewell.

Some respondents and participants are interested to adapt the measure of boiling pond water. People are not willingly interested to boil pond water. But, if there is no suitable alternative, they are to go back to the early stage when people of Ghona used to boil the pond water collected from a pond located outside Ghona. They have decided to go back to their early stages when they used to drink boiling pond water for their safety. Their perceptions in this regard are mainly focussing on putting humpty-dumpty back together again.

"... We'll boil pond water if there is no alternative measure. About 40 to 50 years ago, people of Ghona used to collect their drinking water from a pond located at Mrigidanga (the adjacent village). We'll go to our early environments again in collecting and boiling the pond water to save ourselves from arsenic poisoning." [Focus-group discussions, 2001].

Some people think that pond water is not hygenic and not pathogen-free. If they drink that water, they assume that they would get water-borne diseases like cholera and diaohroea. One respondent said, "... I prefer a deep tubewell in place of using pond water, because people farm fishes in their ponds, they bathe there and the water will not be clean afterwards."

The rural environment in Bangladesh is mainly characterised by a lack of education, the economy is mainly confined to primary production and the people's living standard is very low. Some focus-group participants said that there is a greater chance that pond water will be unsafe by the local illiterate people. If arsenic-free water is available in a deep tubewell, why should they go to a pond for drinking unhygenic water?

> ". . . . Dirty water will enter into the ponds and will pollute the water during the rainy season and the dirt of birds and animals will mix up with the pond water. Children will misuse the pond water and farmers will use it to wash their cattle. People will take a bath in that pond and spread poisons from their bodies. If people are suffering from a rash or skin diseases or eczemas, all the germs from their bodies can contaminate the pond water, and they will wash clothes in it. Therefore, how safe will pond water be? If people drink this pond water directly, then what will happen? Using this water either by drinking or by cooking can spread different types of water-borne diseases. A deep tubewell is the best for arsenic-free water. Since Ghona is a rural area and the culture of the people is rural, therefore, a pond is not useful and hygienic for the people. To prevent these diseases, it is necessary to install deep tubewells on an urgent basis." [Focus-group discussions, 2001].

Apart from those survival strategies, there have been some additional measures that people would like to adopt to prevent arsenic toxicity. The use of camphor (*Korpoor*) in water and the collection of rainwater are the survival strategies. People would like to continue these survival measures until they get better alternatives to arsenic-free water. Some people thought that they could use bleaching powder in purifying the tubewell water or pond water if there is no alternative, but they changed their minds when strong chemical smells (chlorine) followed.

5.5 THE PATIENT-DOCTOR CONTROVERSY

Generally, the poor people who work in agriculture get many types of skin diseases on their hands and feet. They consider this to be a normal aspect of their regular life. One patient in this connection said, ". . . We have heard something about arsenic, but it does not have any importance to us. If we get any sores (*ghaa*) on our palms, we always consider that it is due to ploughing the land or digging the soil with a spade (*kodal* - tool to dig soil) when working in marshy agricultural land (*beel*). It is really is not a disease. We call it swelling spots (*gotta* or *goottee*) on our hand and feet. We have never thought that arsenic could be the cause of it. Many people have got this type of swelling spots on their hands and feet." People generally do not go to a doctor for their swelling spots. However, the arsenic scare has caused confusion and now some people seek medical advice.

Some patients go to doctors several times. They spend a lot of money for the treatment of their swelling spots, but they never feel better. In essence, some patients are not happy with doctors, while vice versa, doctors are not pleased with some of their patients since they are not completing the course of treatment. In such cases, the interactions between patients and doctors are becoming problematic since there is treatment inconsistency. Patients go to a doctor for a quick recovery, but doctors cannot deliver it.

5.5.1 Patient's attitudes to doctors

Some patients complain that local doctors know nothing about arsenic-related diseases. Since arsenic awareness is new in Ghona and no medicines have yet been invented for arsenicosis diseases, most of the local doctors know very little about the pathology and treatment of arsenicosis. They prescribe medicines for the sores (*ghaa*) or swelling spots (goottee) on labourers' palms because the symptoms are similar to those of arsenic-related diseases. I spoke to one patient who went to three different doctors for the treatment of his sores, but when there was no improvement in his health after taking a lot of medicines, he criticised the doctors for their performance:

> ". . . . When I asked about my skin problems, three doctors explained the problems in three different ways and they prescribed different medicines for me. So, how can I trust the doctors? Actually, they know nothing about arsenic. Even if they knew, why did they explain my sores (*ghaa*) in different ways and why did they prescribe different medicines?" [In-depth interview, 2001].

Another patient, in this regard told me:

> ". . . . I went to several doctors for my sores, but I didn't get any benefit from the treatment. I'm now continuing to go to doctor (X) of Ghona *Hatkhola*. He identified my sores as eczema (*eakzima*). He told me not to take medicines so much. He scared me that more medicines can make me crippled (can make my limbs defective). I'm worried about my problems. A few months ago, I went to another doctor (Y). He advised me to rub ointment on my sores and prescribed me to continue medicines. I don't know where the problem is - different doctors gave different opinions and prescribed me different medicines." [In-depth interview, 2001].

The vast majority of people in Ghona cannot afford to doctors' prescription fees and medicines over an extended period. It has been mentioned earlier that patients have to pay a prescription fee for doctors and then they have to pay again for the actual medicines. In some rural areas doctors provide both and only charge for the medicine fee. However, the cost of these medicines is much higher than the market price. Since many patients cannot afford lengthy medical treatment, they are getting worried:

> ". . . . I went to a doctor of Satkhira twice in the last six months. I asked him when I will recover? He then replied, continue this medicine and follow this presceiption and come back here again 15 days later. The prescription fee is TK200.00 (£2.67) for first visit and TK100.00 (£1.33) for each visit later. I've now paid TK300.00 (£4.00) for the prescription fees, but the cost of medicines are not included in this. I'm poor. How can I afford prescription fees like this as well as medicine costs?" [In-depth interview, 2001].

It has been found from the study that patients' perceptions about doctors are not positive since some doctors are rude to poor patients and their treatment procedures are not working well. Haq (2001a) also pointed out the same aspect about patients' attitudes towards contacting a doctor. It is noted here that most of the patients only go to a doctor at a critical stage. They then have very little chance of recovery.

5.5.2 Doctor's attitudes about patients

Some doctors treat patients' problems with negligence and do not indicate the harmful nature of their diseases. Some doctors behave roughly and show harsh feelings to their patients, especially the poor. Some doctors are very commercial in their approach and do not like to provide any medicines to their poor patients, those who are unable to pay the full visit or full prescription fee. One arsenic-affected female patient told me about her experience of a doctor concerning the treatment of her skin lesions:

> ". . . . I've been continuing to go to a doctor for the last two years for treatment of my skin problems. I'm still taking medicines, but I'm not getting well. I asked him, why I am not coming round? He replied, you will recover slowly, I have a lot of patients, don't worry. Those who have taken medicines from me, everybody is cured, so be patient. I also asked him, if the situation gets worse, what will I do? He then replied to that he will provide a different type of medicine. This will be more powerful and act quickly. He asked me angrily, why do you think so much about this disease? He also told me that it is a different kind of skin disease that I have got and that only he can help me to recover from this skin disease." [In-depth interview, 2001].

In government hospitals, the attitude and behaviour of doctors to the poor patients is even more inconsiderate. They do not provide any medicines to the poor hospital patients, although in theory prescribed medicines for a given disease must be provided to poor patients in any government hospital free of charge. A poor and very old arsenic-affected patient told me of his experience when he went to the Satkhira *Sadar* Hospital (a government hospital) that:

> ". . . . Last year I went to Satkhira *Sadar* Hospital and I showed my skin problems to a doctor. This doctor told me to buy medicines, there are no medicines extra here to give me. Then I told him, I'm so poor that I can't afford my food three times in a day. That doctor then told me, sorry, nothing will be given here. If you pay then you will get medicines." [in-depth interview, 2001].

It was noted that some doctors have a tendency to lengthen the treatment procedures in order to earn more money. It is not certain that this allegation is true, but from the discourse mode of analysis, it can be seen that in cases of uncertainty, some doctors do not unveil the real health situation to their patients – they experiment on them and finally refer to other doctors or consultants. This discourse mode of analysis is to view the 'problem' from a higher stance and to gain a comprehensive view about that problem.

5.6 ARSENIC RISK and HEALTH HAZARDS

Many exposures potentially have human health consequences (Brookes *et al*, 1995), but they are not always recognised as 'environmentally-related' (Cole *et* *al*, 1998) health hazards. Arsenic exposures potentially have human health consequences as detailed in a large and varied literature (Abernathy *et al*, 1999; Benramdane *et al*, 1999; Col *et al*, 1999; Del Razo *et al*, 1997; Kamijo *et al*, 1998; Lai *et al*, 1994; Smith *et al*, 1992; and Tondel *et al*, 1999). The pattern of arsenic exposure and its toxic effects can lead to us an understanding of the pattern of environmental health hazards.

A hazard is defined as the potential to cause harm, i.e. a potential source of harm to something of human value (Gerrard, 2000) or a general source of future danger. An environmental health hazard is therefore concerned with the nature and magnitude of harm to human health from a hazard event present in the environment. A hazard is not deemed to be synonymous with risk (www.agius.com/hew/resource/hazard.htm), although it can be a determinant of risk. Risk can be considered as the possibility of suffering harm from a hazard, i.e. it is the likelihood of physical harm or adverse health effect due to any substance or technology (Beck, 1992) or other processes (Renn, 1998).

The USOSHA (US Occupational Safety & Health Administration) has defined health hazard as a chemical for which acute or chronic health effects may occur in an exposed population (www.nwu.edu/research-safety/hazcomm/hazcomm-3.htm). Health hazards may cause measurable changes in the body and these changes are generally indicated by the occurrence of signs and symptoms in the exposed population. The chronic effect of arsenic comprises carcinogenicity, teratogenicity, and mutagenicity. These effects are obviously a concern in the environment. Since arsenic is a carcinogen and its long-term effect on human health is cancer, it can be called a health hazard (Figure 5.2).

Arsenic contamination of groundwater has now posed a serious threat to public health in the study area. Groundwater is the major source of arsenic hazards in Bangladesh. It has been proved from epidemiological evidence that arsenic can have a measurable adverse health effects, especially the possible increased cancer risks, even at levels hitherto considered 'acceptable' (Brown and Chen, 1995; Lewis *et al*, 1999; Lin *et al*, 1998; Smith *et al*, 1998; and Tsai *et al*, 1999).

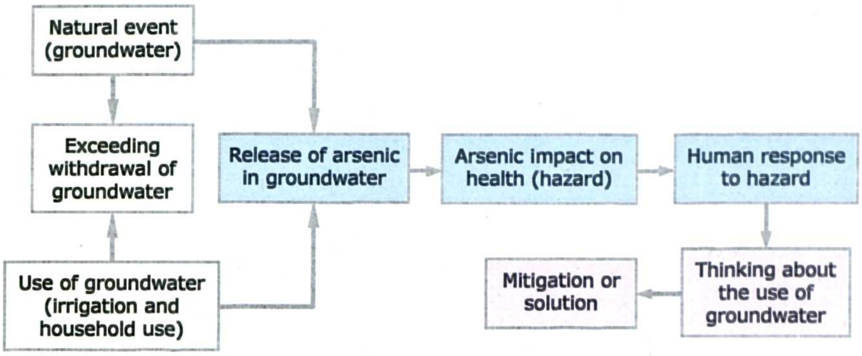

Figure 5.2: Environmental arsenic hazard exist at the interface between groundwater (natural event) and its human use systems.

From the empirical point of view, arsenic can be considered as an environmental health hazard since it represents the single biggest known waterborne chemical risk to health. Many people in the study area are concerned about arsenic poisoning and some arsenic-affected people have already experienced many types of health problem. The health situation of the patients is getting worse and a hazardous condition is developing (Figure 5.3).

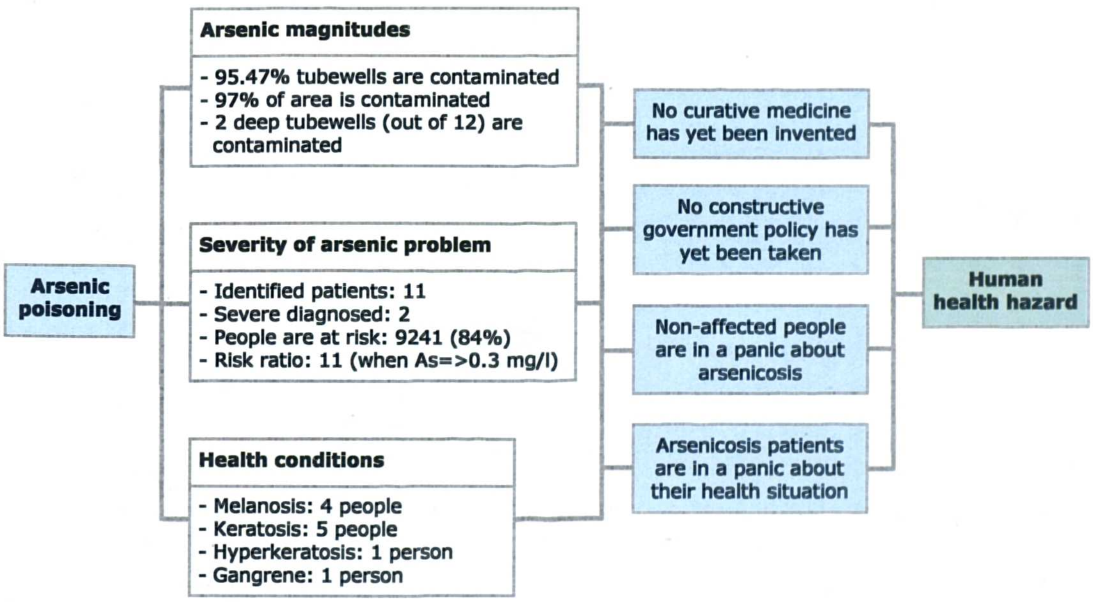

Figure 5.3: Human health hazard posed by groundwater arsenic poisoning in the study area.

We have identified some arsenicosis patients in the study area and they are adopting various coping strategies for their health problems. Some affected people are continuously getting medicines and they do not find any improvement in their health. The worsening condition of patients' health year after year is noticeable. Some say that they are so ill that it is difficult to do any work for a living. Patients affected with arsenicosis a long time are in pain. They become anxious and depressed and some panic about arsenicosis when they come to know that no proper medicines have yet been invented.

5.7 CONCLUDING REMARKS

The rationale and effectiveness of the qualitative mode of analytical procedures have provided insights into the lay understandings of the local people about arsenic and its toxic effects on health. An attempt has been made to uncover patient's perceptions about their health problems and how they manage their regular lives when affected with arsenicosis. The in-depth interviews and the focus-group discussions were mainly adopted for exploring people's perceptions concerning their health problems and their understandings about arsenic toxicity. In addition, all tubewell holders were asked relevant questions during the collection of water samples. This chapter has discussed the exposure to arsenic and its effects on human health, the survival strategies of both the affected patients and unaffected people in the forms of coping strategies and adapting strategies, and the controversy between doctors and patients.

The chapter explored the experience of living with arsenicosis. The results indicate that, regardless of treatment, living with arsenicosis involves living with uncertainty, panic and problematic family issues. Participants demonstrated that their thoughts and behaviours have evolved over time in response to their disease. Winters (1997) showed the same results with respect to heart disease. Some respondents and participants gained an awareness about arsenic impact on health. Individual and focus group strategies for coping with arsenicosis have been identified.

It has been concluded from the overall discussion that the methodological approaches adopted in this chapter are justified. We have examined the aptitude and functionality of qualitative methodology in identifying the overall health situations of patients in the light of their experience. The qualitative modes of analysis adopted in this thesis have been demonstrated as an excellent tool to handle a wide range of verbatim databases in a meaningful form.

It has been found from the discussion that there was a lack of significant opinions from some people when asking them about the conceptual framework of arsenic, risk and health hazard, although local people said something about the core concepts of the issue from what they have heard recently or in the past. For example, their ideas were mainly confined to poison, disease, gangrene, cancer and death. Perceptions of arsenicosis patients were confined to itching, blisters, black spots, and the hard and rough palms and soles that they are experiencing. The perceptions of local people concerning the terminological issues deviate from expert opinions of the issues. This was because they have heard about arsenic from many different sources, and generalised the understandings with core conceptions about arsenic, e.g. poison, terminal disease etc.

In reviewing the literature, there is a focus on arsenic toxicity in the form of the symptoms of arsenicosis at different levels, rather than on the pain that arsenicosis patients are recognising. A qualitative methodology allows a different type of study in which the impact of arsenic on health can be perceived. This chapter has explored the patients' own ideas about their health situation and the management of arsenic toxicity, i.e. what they think and do in terms of survival strategies and the solutions they envisage to their problems.

The study of lay concepts is a flourishing area, which has gained considerably in sophistication in recent decades (Blaxter, 1997). This chapter has privileged the voice of the rural patients, who are the best judges of their experiences and managing their lives. A combination of expert opinions and lay perceptions can lead to better understandings about the health problems caused by arsenic ingestion.

Research on health aspects based on qualitative data remains 'extremely important' (Ong and Jordan, 1997) since it allows for a complementary understanding of the contextual aspects for people's narratives of their own lives (Calnan, 1987; Davison *et al*, 1991; Crawford 1999; and Williams *et al*, 1998). The combination of qualitative data from in-depth interviews and focus-group discussions has enabled a complex understanding of how poor people perceive their health and the factors influencing it.

Arsenic is considered to be a 'natural calamity' in Bangladesh and West Bengal (India) because of its toxicity. In view of the qualitative methodological approaches adopted for this chapter, it can be said that people's perceptions about their health conditions caused by arsenic indicate worse health situations than they have ever faced before.

Quantitative analysis shows the overall arsenic magnitude and its effects on health, with numbers of people affected with arsenicosis, rather than the inherent health problems that the affected people are experiencing. This chapter has explored the health situations of people during their illness. The next chapter (chapter VI) will focus on people's insights about their social problems caused by arsenicosis. Some patients in Ghona are facing social troubles due to ignorance about arsenic. Qualitative research methods will also be employed for the next chapter in performing a social hazard analysis of the study area.

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CHAPTER VI

ARSENIC IMPACT and SOCIAL HAZARDS: PATIENTS' PROBLEMS and THEIR THOUGHTS

CHAPTER – VI

ARSENIC IMPACT and SOCIAL HAZARDS: PATIENTS' PROBLEMS and THEIR THOUGHTS

As with explanations of the impact of arsenic on health (Chapter V), understanding people's perceptions concerning the social hazards related to arsenic is also an important objective of this thesis. This chapter seeks to explore people's perceptions about the terminological issues of social risk and social hazards caused by arsenic poisoning in the last few years. What kind of social troubles have been created due to arsenic-induced health difficulties? How do arsenic-affected local people manage their social problems? These questions will reveal many inherent social problems and will also disclose any changes of social norms by arsenic-affected people. These questions seek to determine how and to what extent people are getting help from different sources as well as the role of government, NGOs, and other organisations in solving the social problems of arsenic-affected people. The chapter also examines people's understandings of arsenic-related social difficulties that they are experiencing and their survival strategies.

The chapter is divided into seven sections. The first section discusses the use of qualitative assessment of the people's understandings about social problems caused by arsenic. Section 6.2 seeks to explore people's understandings around terminological issues of social risk and social hazards. Section 6.3 presents the patients' voices on the effects of arsenic on their social life. Section 6.4 discloses the attitudes of different unaffected people towards the patients. Section 6.5

describes the survival strategies that arsenic-affected people are adopting and section 6.6 describes people's ideas about how arsenic leads to social hazards. Finally, section 6.7 makes some concluding remarks on the overall analysis.

6.1 ACQUISITION of the PEOPLE'S VOICES: QUALITATIVE ASSESSMENT of DATA

Qualitative methods have been employed to measure people's understandings of arsenic impact on their social life and their survival strategies. Arsenic-affected patients, in this regard, are well placed to determine their 'own priorities' (Korboe, 1998) in identifying the impacts on their social life.

The qualitative method elicits in-depth answers (Miles and Huberman, 1994 and Wolcott, 1994) about affected people's social problems. The qualitative approach in this thesis brings forth the in-depth reality about the impact of arsenic on the social life of the arsenic-affected patients and the different survival strategies they are adopting. A wide variety of qualitative methods in terms of a participatory approach, in-depth interviews and focus-group discussions were employed during the fieldwork to explore people's perceptions (i.e. mainly patients' opinions) of the impact of arsenic on their social life and related issues.

In my fieldwork, in-depth interviews and focus-group discussions were used to define people's varied understandings of the impact of arsenic on patients' social situation and their survival strategies. These involved both the sufferer and the non-sufferer (Figure 6.1). The study was designed to bring out the details using 'multiple sources' (Silverman, 1993) of data. PRA methods, participant observation, in-depth interviews, and focus-group discussions were carried out in this regard. As discussed in Chapter V, twenty-three in-depth interviews and five focus-group discussions were accomplished. Detailed interviews, conversation and discussions with different respondents and participants provided insights into how people think about the social problems, social risk and social hazards caused by arsenic.

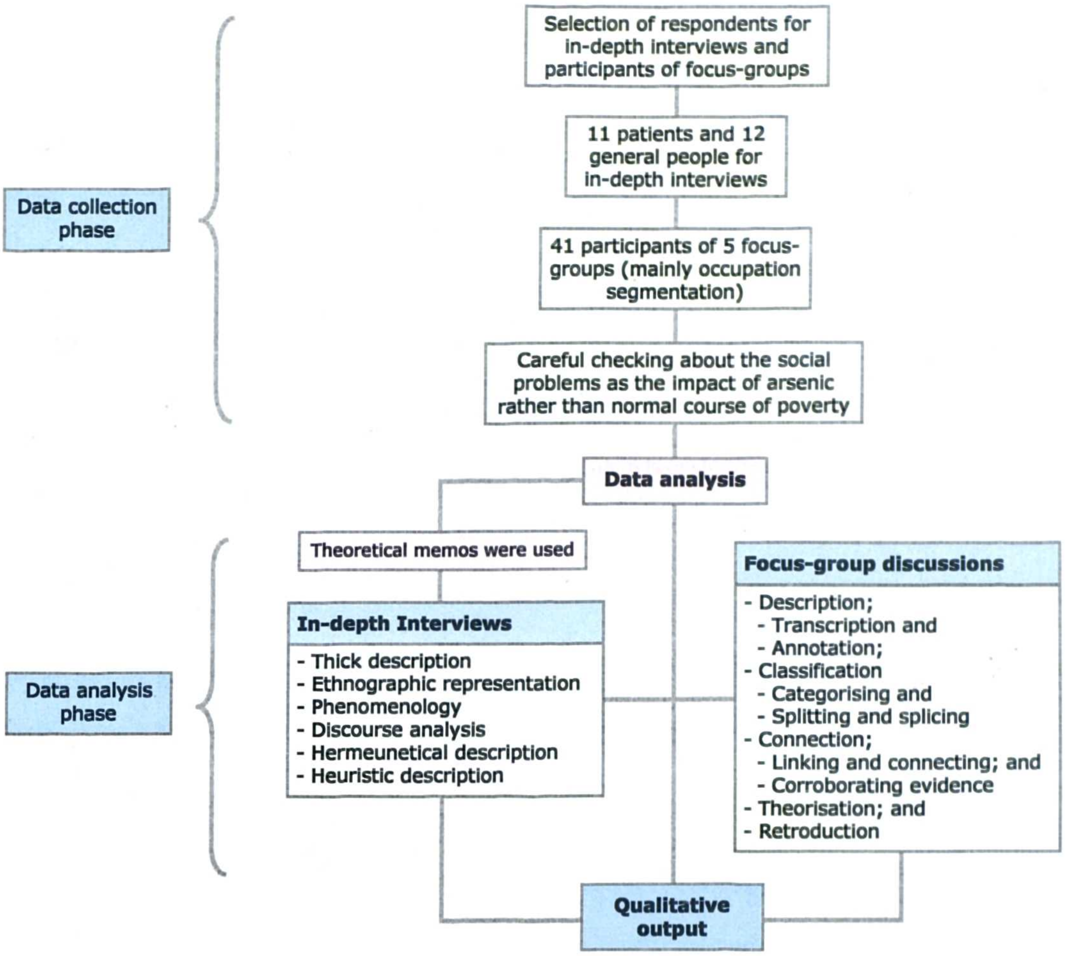

Figure 6.1: Flow chart for data collection and analysis.

In Bangladesh, poor rural people suffer many indignities, humiliations and injustices. During my field survey, I was careful about the social problems of the poor rural people, whether their social problems are the result of arsenic poisoning or the impacts of the normal course of their poverty. I filtered out those social problems which were clearly due to their poverty. It is noteworthy that some respondents and focus-group participants on some occasions indicated that their social problems took place during the recent flood.

The collected qualitative data were analysed and interpreted using different analytical modes. Similar to the Chapter V, different qualitative modes of analysis were helpful to build new understandings. The qualitative analytical modes seek to explore and present rich descriptive narratives by developing valid and reliable concepts of arsenic impact on patients' social life.

6.2 TERMINOLOGICAL ISSUES: PEOPLE'S INSIGHTS

6.2.1 Insights and understandings of 'social risk'

The in-depth interviews and focus-group participants identified different meanings of social risk. These perceptions about 'social risk' from different respondents and focus-group participants have been summarised here in different forms (Box 6.1 and Table 6.1) following the hermeneutical (Myers, 1997 and Ratcliff, 1999) and heuristical (Bergum, 1989; and Bunne, 1999) modes of analysis as well as data abstraction and high levels of interpretation (Bunne, 1999; and Rich and Ginsburg, 1999).

(a) **Chance of having social difficulties:** Most people's opinions of 'social risk' focussed on the 'chance of social difficulties arising' (*saamazik samossai porar shambhabona*). They thought that if there is any chance of social problems due to arsenic contamination, then it could be called a 'social risk'.

BOX 6.1
People's perceptions of social risk
(In-depth Interviews)

Kalam :	Social risk is a 'chance of having social difficulties' (*saamazik samossai porar shambhabona*).
Jhilam :	I think, arsenic could cause 'social problems' (*saamazik samossa*) for the affected patients.
Golam :	People could be at social risk, if they get arsenic-induced disease. People will not make any close relationship with the arsenic-affected patients because of arsenic panic.
Dulal :	Social risk can be defined as 'social hazard' (*saamazik beepod*). If there is any possibility of social injustice due to arsenic poisoning, then it could be said that people of that area are at 'social risk' (*saamazik jhuki*).
Shahin :	If people get arsenic-induced disease, they will be at 'social risk' (*saamazik jhuki*) of many difficulties.
Tuhin :	I don't know anything about social risk accurately, but I think if there is any possibility of social injustice, social isolation and social inequality, then we can say people are at 'social risk' (*saamazik jhuki*).

Data source: Field survey, 2001.
Remarks of respondents from in-depth interviews (names have been changed).

Table 6.1.
People's perceptions of social risk
(Multiple responses)

Concept of social risk	Respondents (Frequency)						
	In-depth interviewees	Focus-groups*					Total
		FG-1	FG-2	FG-3	FG-4	FG-5	
'Chance of getting social difficulties' (*saamazik samossai porar shambhabona*).	5 (4.20)	4 (3.36)	3 (2.52)	4 (3.36)	3 (2.52)	2 (1.68)	**21** (17.65)
'Possibility of social hazard' (*saamazik beepoder shambhabona*).	4 (3.36)	1 (0.84)	5 (4.20)	1 (0.84)	1 (0.84)	1 (0.84)	**13** (10.92)
'Probability of getting social injustice' (*saamazik onnairer shambhabona*).	3 (2.52)	5 (4.20)	1 (0.84)	2 (1.68)	3 (2.52)	1 (0.84)	**15** (12.61)
'possibility of social damage or social harm' (*saamazik khoteer shambhabona*).	1 (0.84)	4 (3.36)	4 (3.36)	3 (2.52)	4 (3.36)	2 (1.68)	**18** (15.13)
'Causing the danger for society' (*saamazae beepoder karon*).	-	3 (2.52)	6 (5.04)	5 (4.20)	5 (4.20)	3 (2.52)	**22** (18.49)
'Odds to social humiliation' (*saamazik abomanonar shambhabona*).	-	2 (1.68)	3 (2.52)	-	2 (1.68)	1 (0.84)	**8** (6.72)
'Probability of social degradation' (*saamazik abbokoyoer shambhabona*).	-	3 (2.52)	4 (3.36)	3 (2.52)	8 (6.72)	4 (3.36)	**22** (18.49)
Total responses:	**13** (10.92)	**22** (18.49)	**26** (21.85)	**18** (15.13)	**26** (21.85)	**14** (11.76)	**119**

Data source: Field survey, 2001 (In-depth interviews and focus-group discussions).
Figures in parentheses indicate the percent of respondents/participants for each symptom.
* Focus groups have been denoted as five categories i.e. FG-1 (Farmers); FG-2 (Teachers); FG-3 (NGO and Govt. officials); FG-4 (*Political* leaders and social activists); and FG-5 (Elected administrators).

(b) **Possibility of Social hazard:** Some respondents recognised the meaning of social risk as the 'possibility of social hazard' (*saamazik beepoder shambhabona*). They concluded that if there is any possibility of danger in society, then it can be said that the people of that area are at social risk. When asked about the social risk from arsenic, some respondents said that they did not know, but others said that if people experience any 'social injustice' (*saamazik onnay*) due to arsenic poisoning, there would be a 'social risk' (*saamazik jhuki*). Some respondents assumed that ". . . If arsenic-affected people are experiencing social problems, e.g. social isolation, social injustice and so on, then their situation could be considered as a social risk".

(c) **Possibility of social harm:** A common perception of 'social risk' (*saamazik jhuki*) is that of the 'possibility of social harm' (*saamazik khoteer shambhabona*). Participants in one focus-group said that "some people from this village are facing many social problems due to arsenic contamination and they have already been isolated and excluded from many social functions, so we can tell that they are at the stage of social risk." Participants in another focus-group said in this regard that "when people will avoid those who are arsenic affected, then the developing situation for the affected people is called a 'social risk' for them."

(d) **Social humiliation:** Another definition given of 'social risk' was 'the likelihood of social humiliation' (*saamazik abomanonar shambhabona*). Such a perception of 'social risk' is mainly confined to the probability of degradation and dishonour for arsenic-affected people. Some participants assumed that if people contract arsenic-induced diseases, they will be at risk of social isolation, social injustice, and social inequality.

(e) **Causing danger for society:** Some focus-group members assumed that 'social risk' means 'causing a danger for society' (*saamazae beepoder karon*). Their opinion is that if arsenic-affected people face personal risk then there will also be danger for society generally.

6.2.2 Perceptions and the configuration of a 'social hazard'

People's perceptions of 'social hazards' varied significantly (Box 6.2 and Table 6.2). These perceptions, apparent through the in-depth interviews and focus-group discussions, have been summarised below (Box 6.2 and Table 6.2).

BOX 6.2
People's perceptions of social hazard
(In-depth Interviews)

Kalam :	Social hazards can be considered as the 'result of negligence' (*tuuschoottar karon*).
Salam :	If people face any social negligence, then the situation could be considered as a social hazard.
Golam :	Social hazards are the result of 'social degradation' (*saamaajik abbokoyaer karon*). If people of a society get disgraced morally due to any arsenic-induced disease, this situation could be called a social hazard.
Jhilam :	The worst social conditions of arsenic-affected people could be called a social hazard.
Belal :	If people are ostracised due to arsenic poisoning, then the situation could be called a social hazard.
Helal :	If people are socially isolated (*saamaaj chutti*) due to arsenic poisoning, they will be suffering from a social hazard.
Shahin :	I think, if people feel 'social loneliness' (*saamaajik ekakitta*) due to arsenic, this will be called a social hazard.
Tuhin :	I think when people of a society are jeopardized in their social structure and social norms, then the situation can be called a 'social hazard' of that society.
Fahim :	If people have any difficulties living in a society, then it could be a social hazard.

Data source: Field survey, 2001.
Remarks of respondents from in-depth interviews (names have been changed).

(a) **Negligence:** Some respondents saw social hazards as the 'result of negligence' (*tuuschoottar karon*). If people suffer from social negligence due to arsenic poisoning, then this situation could be called a social hazard.

Table 6.2.
People's perceptions of social hazard
(Multiple responses)

Concept of social hazard	Respondents (Frequency)						
	In-depth interviewees	Focus-groups*					Total
		FG-1	FG-2	FG-3	FG-4	FG-5	
'Cause to negligence' (*tuuschoottar karon*).	8 (5.13)	5 (3.21)	2 (1.28)	3 (1.92)	4 (2.56)	-	**22** (14.10)
'cause to social degradation' (*saamaajik abbokoyaer karon*).	4 (2.56)	3 (1.92)	5 (3.21)	2 (1.28)	2 (1.28)	2 (1.28)	**18** (11.54)
'Social isolation' (*saamaaj chutti*) and 'social loneliness' (*saamaajik ekakitta*).	7 (4.49)	4 (2.56)	6 (3.85)	4 (2.56)	6 (3.85)	4 (2.56)	**31** (19.87)
'Getting jeopardize' (*jhukipoorna hoaea*) in social structure and in social norm.	2 (1.28)	-	5 (3.21)	2 (1.28)	3 (1.92)	2 (1.28)	**14** (8.97)
'Getting difficulties' to live in a society (*saamaajae boshobasher samossa*).	3 (1.92)	4 (2.56)	7 (4.49)	5 (3.21)	6 (3.85)	2 (1.28)	**27** (17.31)
'Social inequality' (*saamaajik baishammata*).	1 (0.64)	2 (1.28)	3 (1.92)	-	3 (1.92)	3 (1.92)	**12** (7.69)
'Cause to social injustice' (*saamaajik onnay-obicharer karon*).	4 (2.56)	4 (2.56)	4 (2.56)	2 (1.28)	5 (3.21)	-	**19** (12.18)
'Damage of social bond' (*saamaajik bondhon noasto hoaea*).	1 (0.64)	1 (0.64)	4 (2.56)	3 (1.92)	2 (1.28)	2 (1.28)	**13** (8.33)
Total responses:	**30** (19.23)	**23** (14.74)	**36** (23.08)	**21** (13.46)	**31** (19.87)	**15** (9.62)	**156**

Data source: Field survey, 2001 (In-depth interviews and focus-group discussions).
Figures in parentheses indicate the percent of respondents/participants for each symptom.
* Focus groups have been denoted as five categories i.e. FG-1 (Farmers); FG-2 (Teachers); FG-3 (NGO and Govt. officials); FG-4 (Political leaders and social activists); and FG-5 (Elected administrators).

(b) **Social degradation:** Some respondents recognised the meaning of a social hazard as the 'cause of social degradation' (*saamaajik abbokoyaer karon*). If people are disgraced morally for any reason, this is one form of social hazard.

(c) **Social isolation:** Some arsenic-affected patients defined social isolation (*saamaaj chutti*) as a form of 'social loneliness' (*saamaajik ekakitta*). When asking them about the social hazard of arsenic, some respondents said that "if people have any social problems due to arsenic-induced disease, they will be at the stage of social hazard to arsenic". It is noted that many in-depth interviewees did not have any understanding about social hazard, but some respondents, in this regard said, "when society is challenged in its social structure and social norms, then the situation can be called a social hazard of that society". Moreover, some respondents said that "if people have difficulties living in society, then this could be called a social hazard".

(d) **Social inequality and social injustice:** Some focus-group participants considered a 'social hazard' to be 'social inequality' (*saamaajik baishammata*) and 'social injustice' (*saamaajik onnay*). Their perceptions are mainly confined to the threat of people's societal characteristics. The loss of social norms and moral values due to 'social degradation' and 'damage of social bonds' are the resultant forms of a social hazard. Some focus-group participants assumed that if people experience social problems or social difficulties and lose their social structure and social norms due to arsenic-induced disease, then this situation could be called a social hazard.

6.3 ARSENIC EXPOSURE and SOCIAL EFFECTS: PEOPLE'S VOICES

What do arsenic-affected people think about the social problems caused by arsenic-related diseases? The answer will help us to reveal the social problems that the arsenic affected people are experiencing from arsenic rather than the recent flood experience. The qualitative methods were employed for studying people's own understandings about arsenic impact on their regular social life and the difficulties that they are experiencing from their disease.

6.3.1 Voices of arsenic affected patients

All of the known arsenic-affected patients in the study area were interviewed about the changes in their normal social life and about the societal problems caused by arsenic-related disease. Along with the clinical manifestations, there has been a tendency for social problems to occur in the study area. These social consequences of the arsenic crisis are far-reaching and tragic. Some rural people, due to a lack of access to technical information, consider arsenicosis to be a curse of nature.

Some patients are experiencing problems with employments. When employers came to know of their arsenic problems, they are not allowed to work. In some affected families, wives, sons and daughters are working in place of household heads. It has been found from the study that one seriously arsenic-affected patient has not been working for two years. His wife is working in agriculture for money for their family sustenance. Some patients are mentally so upset in their health and social situation that they are planning to continue medication for a long time. They think that if their health condition gets worse, they will face more problems both from their families and the community and that they will have nothing to do. The social problems caused by arsenic are briefly discussed below.

A tendency to ostracise arsenic-affected people: This section investigates the sequential development of social problems and the meanings that arsenic-affected patients attach to them. There is a tendency to neglect arsenic-affected people in Bangladesh since it is thought that arsenicosis is like leprosy or some other contagious diseases (Hassan, 2000). If any new disease appears anywhere in rural Bangladesh, there is a tendency for people of that area to avoid and to isolate the affected people. Within the community, arsenic-affected people are barred from social activities and often face rejection, even by their immediate family members. Khan (2001) also points out the same kind of social problems for arsenic-affected people. Bearak (1998) unveils the life-history of one Pinjira Begum, 25, an arsenic-affected patient - who was seriously ill and many indignities affected her life. The social problems of similar arsenic-affected patient in the study area are depicted in Box 6.3.

BOX 6.3
(Social situation of an arsenic-affected patient)

Mr Jhilam lives in Mollapara at Ward - 1 in Ghona *Union*. He is about 22. He lives with his parents. He is only educated from the Kathanda Primary school. Mr Jhilam is working as a farmer and a daily labour like his father. He ploughs his own land and also toils in the paddy of other people. He earns about TK25 (£0.30) daily. He mainly works at the *Dat-Bhanga Beel* and he always drinks water from a tubewell located at this beel (Tubewell_id: 183). The arsenic concentration in this tubewell is 0.400 mg/l. In addition, his family members always collect drinking water from the nearby tubewells (Tubewell_ids: 114 and 118) having the concentrations of arsenic of 0.356 mg/l and 0.157 mg/l. They use tubewell water for drinking purposes and pond water for cooking purposes.

Mr Jhilam did not know anything about arsenic and related diseases prior to my fieldwork. He has come to know about arsenic from me. He has a radio and has heard about arsenic, but he did not give any importance in it since he didn't know what arsenic is and he didn't know who were the people affected with arsenic-related diseases.

Mr Jhilam is affected with arsenicosis, having black spots on his feet and hands for six years. He went to several physicians (allopathic, homeopathic and ayurvedic physician) several times for treatment. He takes medicines and uses ointments as per the prescriptions of doctors, but there is no improvement.

After getting this disease, some of the friends of Mr Jhilam no longer came to talk to him. One of his closest friends told him, ". . . Please don't come to me, if I touch you then the disease you have got will contaminate me." They assume the arsenic related diseases are contagious. Mr Jhilam added that his friends are now trying to avoid him and to isolate him. Moreover, there is an increasing tendency to avoid him, even among his family. He is indirectly isolated in his family. ". . . My parents do not tell me anything directly, but I can understand their feelings and distance," said Mr Jhilam. His parents are very aloof in this regard. In addition, his parents told him frequently, ". . .Go to the physician and show him your problems." But, apart from the social problems, he focuses on the problem of getting work as a daily labourer.

Data source: Field survey, 2001.
Remarks of an arsenic-affected patient (name has been changed).

Ethnographic investigation uncovers that, during their sickness, some patients experience problems like social isolation. Generally, people have the tendency to ignore the patients in many respects. It has been found from the field survey that patients having arsenicosis are experiencing social problems.

It is interesting that most of the people do not know about arsenic and related diseases, but some of them considered the disease as a contagious one, even though they do not know whether people are affected with arsenicosis or not. Chowdhury (1997) and Milton *et al*, (1998) reveal similar stories in their research. In addition, during a survey in Marua village at Jessore (June 1999), it was observed that arsenic created unmeasurable social problems. Arsenic affected three wives (out of 37 affected women) were sent back to their parents and two wives were divorced (Hassan, 2000).

Some patients experience social problems due to the visibility of '*zengoo*' (black spots). This symptom is the most common among farmers and workers in the study area. The extreme stage of this *zengoo* makes some patients worry about terminal disease and, when unaffected people come to know and see the extreme conditions of this *zengoo*, they try to avoid these patients. One seriously arsenic-affected patient, in this regard, told me that:

> ". . . . Some people in *Hatkhola* avoid me indirectly. When I go to any shop for my daily shopping and even to a tea-stall for a cup of tea, some people move away or try to leave. I don't know why do they do this. They will not realise my problems until they get this disease themselves. I am very upset at this situation." [In-depth interview, 2001].

Anwar (2001a) pointed this out in his research on the impact of arsenic on social life. He quotes the example of an eighteen years old girl who often gets seriously sick and cannot get out of bed. When she was in school (Class 8) she got arsenic lesions all over her body and her friends never visited her (Anwar, 2001a).

Difficulty in getting work: Some patients thought that the difficulty of getting daily work or interruptions of daily labour are major consequences of arsenic poisoning. If an adult member of a family is affected with arsenicosis, there is a problem to maintain the income stability of that family. Patients in the study area thought that the difficulty of getting regular labour work creates problems of sustaining the family. Most of the patients are engaged in work either in agriculture or as daily labourers. They earn money on a daily basis and so, if they are absent due to sickness, they will not get any money for the day that they did not work. When employers look at the palms or skin lesions of arsenic-affected patients, this affects their attitude. Most patients thought that their skin lesions are the cause of getting work only inconsistently. Some said that when people come to know that they are sick, then nobody is willing to provide them with any work. One patient suggested in this regard that:

> ". . . . The main problem is to get outside labour work. The work provider knows my health condition. One day, he told me that you are sick, you are not able to do any work. Go home and take a rest. When you will recover then you will come for the work. I will give you the work then." [in-depth interview, 2001].

It has been found from the study that patients living with chronic arsenicosis are engaged in work only in an irregular way. They are very poor and are the only earning members in their respective families. In addition, arsenic-affected women are unable to carry out domestic work. Problems arise when they are refused their regular daily outside work. Bearak (1998) noted that qualified candidates with arsenic symptoms called for interview are often not offered a job. But, I did not find this type of job refusal since men and women of most families in the study area are daily labourers for which they do not need an interview.

Schooling the children: School children are also affected by arsenic poisoning. Through the discourse analysis, children's experiences can be disclosed about their school life, i.e. how they manage their schooling during their illness. In rural Bangladesh, if anybody gets any unknown disease, others consider the disease to be a contagious and then they think that this disease could contaminate them if they are in physical proximity. School children are also experiencing this situation. Friends of affected children avoid sitting close to them and keep their distance. They do not like to share books, pencils and so on, and they do not play with affected children in school. In addition, teachers may restrict their access to school. An example is Taslima Akther, aged 10, a girl who developed black spot on her palms and soles and who is facing problems in her school. She told me of her problems:

> ". . . . Nobody takes their seat beside me in school. They do not like to talk with me, and do not share books. Nobody likes to play with me in school. When I play, some children shout 'don't touch her, don't play with her, she's got arsenic'. I will not go to school." [in-depth interview, 2001].

Some children with arsenicosis symptoms go to school hiding their problems. They do not like to show their skin disease to anybody. One school child, in this regard, told me, "I've got sores on my palms and if I show them or talk about this, my friends will not play with me in school." Relevant literature shows evidence in support of this situation. Children with symptoms are not sent to school in an effort to hide the problem (World Bank, 1999) but their entrance to school is also restricted because of this illness (Milton *et al*, 1998). This situation is a serious impediment to the children getting education.

In-family situation: Some patients are also experiencing some sort of problem in their own families. There is an increasing tendency to avoid patients in their own families - they are neglected and indirectly isolated. The hermeunetical mode of analysis provides here a 'philosophical grounding' (Bleicher, 1980 and Myers, 1997) for understanding patients' perceptions about their real social difficulties. The statements of one patient affected with arsenicosis are treated with hermeneutics, displaying his voice, for instance:

> ". . . . My parents do not tell me anything directly, but I can understand their feelings and the distance they are making. One day, when I took rest on my bed, my mother told me, why are you sleeping so much? Go to your work and earn money for the family." [In-depth interview, 2001].

Hermeneutics can present this social condition through the voice of patients affected with arsenicosis. Children are not close to their parents and parents feel hesitant about being close to their children. Moreover, husbands keep a safe distance from their wives. A father suffering from arsenicosis for four years told me, ". . . Two of my sons try to avoid me tactfully - they do not like to come close to me. I can understand their situation, but I never let them know about my health problem. It is an appalling situation in a family atmosphere." Parvin Akther, 17, a young woman who developed black spots on her palms and soles of feet and skin lesions on her whole body is facing problems in her family. She told me, ". . . My parents are rude to me. I have never seen this behaviour before these sores appeared on my body. Probably, I am a burden to this family.

I am really upset." Zaman (2001) points out similar situations in the families of arsenic-affected patients.

Women are socially more vulnerable and they are the worst victims. Roy (1998) also finds the same in his research. Jarina Akther, 31, a woman who developed blisters and black spots on her body is being neglected by her husband. He does not like to talk frequently to her now, and he does not ask her about her health situation. Some of the literature cites evidence that women with arsenicosis symptoms are unable to get married (Chowdhury, 1997; Haq, 1999; WHO, 1996; and Zaman, 2001) and that some affected housewives are divorced by their husbands and even forcibly sent to their parental home with their children (Haq, 1999; Milton *et al*, 1998; WHO, 1996; and World Bank, 1999), although I did not find this in my study area. The parents of one girl told me about their problems,

> ". . . . People sometimes ask me, what is developing on your daughter's palms? Why don't you go to a doctor? You will face problems in the marriage of your daughter. We are upset at our daughter's present health condition." [In-depth interview, 2001].

More young women and their parents are aware of the social problems than actually have arsenicosis. They fear that a victim will be a burden to the family. The parent of one young woman said: ". . . What can I do now? My daughter has got blisters on her whole body and it is gradually getting worse. If she does not recover quickly nobody will marry her. If she is in good health, she can help me in my house work. Now she is sick and she cannot do any work." Anwar (2001a) reveals the distrustfulness of parents about the health of their daughters.

Generally, people thought that arsenic-related diseases are contagious and almost all of the arsenic-affected patients are leading constrained lives. In fear of such social problems, people feel hesitant about expressing themselves about their illness. Some patients were not interested to tell me about their health problems in the presence of others. Some expressed their fear when they came to know that they had arsenicosis. One patient commented that: ". . . I don't show my hands to people, and I try not to tell my problems to anybody. If people come to know my health condition they will not be cordial with me." It is noted that all of the patients in the study area are very poor and they are experiencing a hard test both in terms of economic disadvantage and social injustice due to their illness.

6.3.2 Voices from unaffected people

Some unaffected people were also chosen for in-depth interviews and focus-group discussions in order to get their perspectives about the impact of arsenic on social aspects. Their perceptions regarding arsenic impact on peoples' social structure will focus on what the unaffected people think about arsenic-affected patients. In this regard there are noticeable variations within and between focus-groups with respect to different understandings.

In a general sense, unaffected people's perceptions about the impact of arsenic are mainly confined to the general social problems that the poor people are experiencing, i.e. social degradation, social injustice, social inequality and so on. Some respondents/participants consider that arsenic-induced diseases are causing not only social difficulties for poor patients, but also creating serious concern among the unaffected people. One respondent told me that: ". . . All of the arsenic-affected patients are thinking about the recovery of their health, but we the unaffected people are not in a good situation either. We are always worried about arsenic. If arsenic attacks us, we will face health and social problems like the poor arsenic-affected people."

Some participants thought that arsenic can cause patients to be socially shunned. One unaffected respondent told me that:

> ". . . . I have seen a patient with sores on his palms and skin lesions on his body. He doesn't like to come out from his home. He is always in a depressed mood and doesn't talk to anybody freely and frankly." [In-depth interview, 2001].

It is the unaffected people who are creating this injustice to the patients. Some people are angry about the patients, since they are felt to have a contagious disease. They thought that patients should either stay in their homes or that they should leave the village. A participant in one focus-group said: ". . . If anybody is affected with gangrene, who will meet him? Who will go close to him? People will always make a safe distance from arsenic-affected patients because of arsenic panic. Everybody in this village is scared about arsenic."

Some people, on the other hand, are sympathetic to the patients and no fault is attributed to them. They see it is a natural phenomenon and everybody can get this disease. There is the opinion that people should respect the patients. If the unaffected people are also attacked with arsenicosis, then what will in turn happen to them? Will they be ignored or not? Some respondents are scared about arsenic in thinking that if arsenic attacks them, they could be treated the same by their neighbours, friends and family members as the patients are experiencing now. Some participants of focus-groups pointed out that arsenic is damaging the social bonds between patients and unaffected people.

> ". . . . When Mr Kalam comes to *Hatkhola*, people in general don't like to talk with him. Mr Kalam is seriously affected with skin lesions and his body is full of sores. People are panaroid about his sores and they keep a safe distance from Mr Kalam." [Focus-group discussion, 2001].

There is a difference between the perceptions of affected and unaffected people concerning the impact of arsenic on the social situation. Arsenic-affected patients focussed mainly on their own social experiences; while unaffected people emphasised the worry about arsenic that they are experiencing.

(a) Patient's perceptions regarding the social impact of arsenic-related diseases are mainly confined to social isolation, social ignorance, social injustice and so on. All of the patients focussed on the social problems that they are experiencing both in their families and in society. They also made a comparison of their status before and after getting the arsenic-related diseases.

(b) The perceptions of unaffected people regarding the arsenic impact on their social life are far different from that of the affected patients. A considerable number of unaffected respondents and participants assumed that arsenic-affected patients were mentally isolated since they know that arsenicosis is a terminal disease and no curative medicine has yet been invented. They thought that arsenic-affected patients are mentally depressed and this keeps them isolated.

Some respondents and participants mentioned that arsenicosis patients are self-isolated and nobody imposes this on them. They thought that when people get this fatal disease, they become weak morally and keep themselves separate from society. Patients' perceptions contradict the opinions of the unaffected and their opinions focussed strongly on the social injustice to themselves.

6.4 ATTITUDES TOWARDS PATIENTS

Generally, patients are experiencing different sorts of social problems. The previous sections painted a picture about what kind of social problems are being experienced by patients. This section reveals the attitudes of different people to arsenic-affected patients in their society. Some patients are trying to adjust to their social environment, while others are not.

6.4.1 Attitudes of tubewell holders

Some patients complained that some tubewell holders misbehave towards them and do not give them access to their tubewells for collecting water. One patient, in this regard told me, ". . . I used to go to Mr Mollah's tubewell (Id_223) for collecting drinking water. When he has come to know that I got skin lesions on my body, he then told me not to collect water from his tubewell. He also told me that I could spread this disease to other people." Some unaffected people also face problems in collecting water from tubewells. Some tubewell holders tell poor people, ". . . Don't disturb us, sink a new tubewell for yourself and tap water from it".

It has been found in this study that not only the patients, but almost all of the poor people have problems with tubewell holders. Some people at the location of a deep tubewell (Id_337 in Ward: 6) told me, ". . . This is a government-owned deep tubewell. We have the right to access this deep tubewell, but this Ward Member and his family members always make problems for us to collect water. What can we do now?" When I raised this issue in a focus-group of elected administrators, the member of Ward - 6 told me, ". . . No, I never told them not to collect water from my deep tubewell. They always quarrel during the collection of water. They collect water from early morning to mid-night and we are tolerating the noise from tubewell tapping and shrill unwanted sounds from them." He also told me that another deep tubewell in his ward is essential to reduce the pressure on this deep tubewell.

6.4.2 Attitudes of local leaders

Some patients focussed their opinions on percieved social injustice and the 'social negligence' of the local village leaders (*grammo mattobbar*). When patients go to them for help, some leaders play a positive role and others less so. My fieldwork shows that some leaders try to help the patients by providing them with financial support, moral help and advice; while others make commitments, but do not then do anything for the patients. One arsenic-affected female patient told me about getting help from a local leader:

> ". . . . When I came to know that I am affected with arsenic, I went to Mr (X) for help. I told him everything and he gave me money for medicines and also told me that he will arrange a consultation with a doctor about my health. I am very pleased with him." [In-depth interview, 2001].

On the other hand, one patient told me about the attitude of a local leader in this regard:

> ". . . . What can I do for you? I am not a doctor. When you have got a disease, go to a doctor for your treatment. Take medicines, you will come round. If you are in political trouble or other problems, then I can help you. Only a doctor can help you." [In-depth interview, 2001].

Most of the local leaders try to avoid arsenic-affected patients, and they do not like to make any link with them in any respect since the start of the arsenic panic. Moreover, some leaders have come to know that since arsenic-affected patients never improve, there is less reason to do anything.

6.4.3 Attitudes of NGOs

Some patients have been to NGOs to get credit. These patients do not have any work to sustain their families and they are at the stage of selling their assets. When there is no alternative for them, they had decided to seek financial help from the local NGOs. Patients generally thought that NGOs could help them as they are working in many socio-economic development works as well as distributing flood relief to the poor and flood-affected people. One patient was optimistic, but he got a negative response.

> ". . . . Why do you need credit? How can we help you? You are a patient and you are so sick thet you will not work hard. We don't know whether you will be able to pay the instalments in time or not. When you recover, we will help you." [In-depth interview, 2001].

Nobody in the study area appreciated the role of local NGOs in helping poor people. The role of NGOs and their attitudes will be discussed in the next chapter as part of their role in the arsenic mitigation process.

6.4.4 Attitudes of elected administrators

Patients had mixed experiences from their own elected local administrators (chairman and members). Generally, in rural Bangladesh, when people cannot get help from any other source, they go to their representative. People tend to trust their representative more than any organisation. There is a direct link between lay people and the elected administrators. Some patients went to their respective representatives, but they did not get anything except sugarcoated commitment. One arsenic-affected patient told me about his experience:

> ". . . . I requested him (member) to tell the people in my vicinity not to make any problems for me. He replied, 'Oh, yes, I will do it for you, no problem, don't worry'. He then asked me, 'why don't you go to a doctor for treatment? Is it not a good decision to continue the treatment'?" [In-depth interview, 2001].

Other elected administrators told patients directly that arsenic mitigation is not part of their work. One patient in this regard told me about the attitude of a member towards him, ". . . Why do you come to me? I cannot do anything for you. It is not my duty to deal with arsenic. Don't come to me further about arsenic, I'm scared about it." Another member told an arsenicosis patient, ". . . You did not cast your vote for me. Don't come to me for any help. I will help my men first."

6.5 ARSENIC IMPACT and SURVIVAL STRATEGY

How do local people manage their social problems caused by arsenic? The answer to this question will help us to uncover the social conditions of arsenic-affected patients as well as the survival strategies that they are adopting. The continuous worsening of the health situation caused by chronic arsenic ingestion makes patients socially shunned. Patients with arsenic-induced diseases told me their opinions about how they manage their social problems. The survival strategies adopted by arsenic-affected patients can be viewed as (a) coping strategies and (b) adapting strategies.

6.5.1 Coping strategy

In a coping strategy, almost all of the patients took an immediate and temporary response for survival into their society; while some patients have already surrendered to their fate. What strategies do patients use to cope with social injustice? They have a combination of coping strategies that are employed during their critical social contracts with people in general, local political leaders, NGOs, social workers, elected administrators and so on. Respondents from the in-depth interviews gave varied opinions about how they managed their social problems caused by arsenic-induced diseases.

The first strategy: This strategy involves keeping a safe distance from the unaffected people in order to avoid social embarrassment. Patients with serious arsenic infection do not like to go to outside, but some patients with minor infection move easily outside, but they are worried that their health condition will worsen. So two types of coping strategy are being carried out: (a) patients stay in their homes and (b) avoiding social activities and public relations.

The seriously affected patients experience different sorts of social problems. While less affected patients try not to disclose their health problems, the majority of arsenic-affected patients do not feel able to go outside with their 'sores' and 'blisters'. They think that if they go outside of their home, people will make hurtful comments to them. One patient in this connection told me that:

> ". . . . One day I was at the Ghona *Hatkhola* for my regular green vegetables. Somebody then started to talk about arsenic poisoning in my presence and at a certain point they made a criticism about my health. They even asked me why am I spreading this disease? I am very distressed about this situation. I have decided not go outside for any reason if I can avoid it." [In-depth interview, 2001].

Some patients have decided not to attend any social activities and social functions, and even not to continue with many personal relationships. One seriously affected patient told me, "I participated in a marriage ceremony and some people made problems there. I realised the situation and came back home. It was a really embarrassing situation for me and for the invited people also." Moreover, very close friends may isolate the arsenic-affected patients in different ways since they think that arsenic is a contagious disease. Keeping this in mind, some patients always avoid public situations, but try to keep in touch with their very intimate friends.

The second strategy: The second strategy covers coping with in-family problems. One affected patient experiencing family problems told me that, ". . . After getting these sores on my palms, I am facing ignorance from my parents. I have decided not to talk with them and not to meet them. I think I am a burden of this family. Everybody in the family is rude to me." It has also been found from this study that arsenic-affected children try to keep a safer distance from their parents. They do not use and share the common objects of the family. One mother told me, ". . . My son seldom comes to me. He does not share the common plates and bowls - he uses his own. I do not know why is he doing this."

Some patients, especially young women have problems since it is difficult to arrange a marriage for an arsenic-affected woman. People are generally are not interested in making new relationships with anybody in an affected family. One arsenic affected young woman in this regard told me with sorrow that:

> ". . . . I am about 19. My parents are always worried about my marriage. I have decided not to marry. I want to go out from this place. I will work in a family as a maidservant in a different area. I hope it will make my parents happy." [In-depth interview, 2001].

The third strategy: The third strategy covers school children affected with arsenicosis. Affected children do not have easy access to school. They cannot play with their friends. Some of their teachers neglect them. Some children now refuse to go to school further - they want to discontinue their education. They may have already missed a significant number of school-days. Some parents of these children have decided to withdraw them from school. One parent of an eleven-year-old child told me, ". . . I have decided not to send my child to school. If there is not a tolerable environment and the teachers do not take care of them, why should I send my child to that school? If he stays at home, it is better for his mental health."

On the other hand, some children do not reveal their arsenic problems. They cover them up in school so that their friends will not find them out as arsenic affected patients. These children would like to continue with their education. A mother of a ten year old girl explained to me, ". . . My daughter always avoids appearing in public. She goes to school covering herself (*borkha*) to make sure that no one sees the skin lesions that she has developed during the last two years." When I asked this girl about her situation, she added here that:

> ". . . . My mum strongly advised me not to show my skin lesions to anybody and not to say anything about my problems. My friends asked me why do I wear such a 'borkha'? I cannot play with my friends if I am covered with this 'borkha'." [In-depth interview, 2001].

6.5.2 Adapting strategy

By an adapting strategy, I mean that patients have taken a long-term view in order to solve their social problems. What measures of adaptation do arsenic-affected patients use to prevent social problems? Are these strategies effective? Some patients took decisions to solve their social problems quickly and some of them pointed out a combination of adapting strategies for the long run. Apart from this, many unaffected people are scared about arsenic and they do not know whether they have got arsenicosis or not. They thought that if arsenic attacks them, they would be as isolated as the patients are now. They have already taken measures to prevent arsenic poisoning. If arsenic attacks them, what will they do? This question will reveal their long-term strategies to prevent the social hazard.

Individual measures (access to treatment and prevention): Some seriously affected patients think that they will continue to take treatment for a hoped-for recovery. Although the continuation of treatment is an expensive adaptation, some patients thought that this measure will stop them getting worse. They thought that if their health improves, there will be no problem to live in their society, or they could live in their society with only a little hesitation. In a question concerning this measure and its effectiveness, one patient replied:

> ". . . . What are the other alternatives? I think this is the best possible way to save youself from social injustice. If you continue the medication for a long time, you could get well and if you are well, why social isolation? People will do nothing if you are well." [In-depth interview, 2001].

Some patients think that drinking filtered water or boiling water will remove their health problems. Recently, they came to know that arsenic-free water is the only medicine to prevent arsenic. Boiling surface water and filtering are the obvious measures to take. One patient told me, ". . . If I can get arsenic-free water by boiling pond water, I will do it. This arsenic-free water could cure my skin lesions and if this happens, the social isolation that I am experiencing now will disappear."

Household support measures: We have seen that arsenicosis leads to changes in work responsibilities inside and outside the home for the patients, and, in the case of affected children, to changes in school attendance. Patients are physically unable to conduct any laborious work in agriculture and there is a reduction of income support for the family. In such cases, degrees of reliance on family members increase in order to sustain the household economy of patients. Family members in such cases input their time in different works to contribute financial support to sustain the household economy. The wife of one patient in this regard told me that:

> ". . . . My husband is unable to work in agriculture. His hands (palms) are full of 'zengoo' and nobody wants him. So, I go to agriculture and earn some money. My daughter also works and contributes to the family. Until he improves, we will continue to do it." [In-depth interview, 2001].

Some arsenic-affected children are experiencing different social injustice in their school as has been pointed out earlier. Some parents of these children withdrew them from the school. But others decided to continue to send their children to school or leave the village. The father of one affected girl told me, ". . . I will leave this village for my daughter's future and safety as well as my safety. If she faces more problems in her school, we will leave this village".

Community support measures: This section discusses measures by the community for the affected people, although society has already rejected and isolated them in many ways. Some of the patients and their families respond to requests for more information about arsenicosis in their communities. They have made links with different people and bodies thinking that if they could establish a relationship with some renowned people, social activists, political leaders and elected administrators, then they could save themselves from any social injustice.

This policy can be seen as an adaptation mechanism at the community level. They have already arranged a number of meetings that took place at the community level to address arsenic poisoning and its solution. According to meeting resolutions, they have already met the local UNO (**U**pazila **N**irbahi-[executive] **O**fficer) for taking urgent steps to provide people with safe drinking water. They discovered the general arsenic situation of their village from me. In addition, some people in different organising bodies have planned awareness campaigns with the inclusion of arsenic messages in existing health and education programmes. One patient gave his opinion on this community strategy:

> ". . . . I have decided to make a close link with many people of this village. People of this village are scared about arsenic and they are planning to tackle the problem. We have already taken a decision to propagate the nature of arsenic problems to the villagers. I hope, in this way, people will become aware about arsenic and they will learn not to avoid the affected people." [In-depth interview, 2001].

Some respondents and participants have taken precautions to save themselves from arsenic poisoning. They mainly decided to work together at the community level:

> ". . . . It is better to work together. If we can share our problems with each-other, no problem will appear beyond us. We have taken measures to solve arsenic problems. If we learn from the experience of the affected people about their problems, it will be helpful in formulating an adapting strategy." [Focus-group discussion, 2001].

Behavioural adjustments: These are the indirect measures for affected people to survive in their society. Under these behavioural adjustment measures, patients try to regulate their regular activities with regard to their disease and social problems. At present, patients do not have any access to some tubewells due to social constraints. One very poor patient, told me, ". . . What can I do now? I do not have any access to the deep tubewell. I told my wife and son to collect arsenic-free water from that deep tubewell.

I have come to know that the use of this water could cure me." In addition, some patients have reduced the consumption by different family members of staple food and other consumption items over the long-term. A report published by the WHO (1999) has also pointed out this reduction of staple food by arsenic-affected family members.

From my field survey, I have found that unaffected people mainly focus on measures to prevent arsenic-induced diseases rather than the existing social problems which the affected people are experiencing. Their perceptions mainly concentrate on how to escape from arsenic poisoning. They are less concerned about saving the presently affected people.

6.6 SOCIAL RISK and SOCIAL HAZARDS

Health risks and health hazards were discussed in the previous chapter. Moreover, there was a brief description of the literature concerning hazards and risk. The current chapter has focussed on arsenic risks and social hazards. Along with the potential human health consequences, the social impacts of arsenic exposure have been covered in the literature (Ahmed, 1999; Alam, 1998; Bearak, 1998; Chowdhury, 1997; and Hussain, 1999). The toxic effects of arsenic can lead us to an explanation of the pattern of social hazards.

A social hazard is concerned with the characterisation of nature and the magnitude of harm to people's social norms and social structure from a hazard event. Social hazards may cause disruption of social norms of affected people and this change is generally indicated by the occurrence of social injustice, social incidents and social isolation in the exposed population. These resultant social effects of arsenic are causing social hazards in the study area (Figure 6.2).

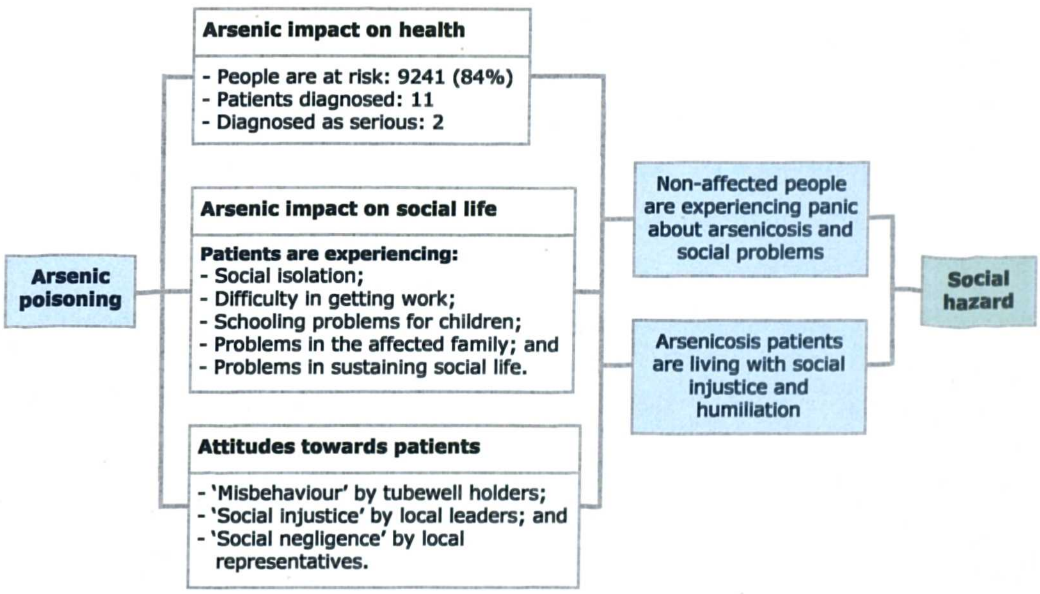

Figure 6.2: Social hazard posed by groundwater arsenic poisoning in the study area.

From an empirical point of view, arsenic can be considered as a social hazard if it represents the single biggest known risk to people's social attitudes, whether measured in terms of 'social degradation' or 'social injustice'. People in the study area are concerned about arsenic poisoning and there are arsenic-affected people who are already experiencing many types of social problems, and a hazardous social condition is developing generally.

6.6.1 Social injustice due to arsenic impact

Arsenic is not only the cause of toxicity to human health, but it also results in major social dislocation for the affected people. Patients identified in the study area are adopting various survival strategies for their social problems but many are continuously facing hostility when people have come to know their health situation. One arsenic affected patient told me about the attitudes he is continuously facing:

> ". . . . What can I do now? I'm very upset about the social problems that I have been experiencing after getting this skin lesion. Everybody in this village always treats me with disdain. They are rude and angry and I do not get any sympathy from anybody. I feel that it is unsafe to live here." [in-depth interview, 2001].

Some patients assumed that if their situation worsens then they will not be able to live in their homes any more.

6.6.2 Social isolation and social pain

It has been found that patients in the study area are not only experiencing physical pain from their ill health, but also social pain. What do arsenic affected people think about the social consequences of arsenic-related diseases? There are some social risks that unaffected people are not aware of, but the arsenic-affected patients can measure these risks on the basis of their practical experiences. The social risk concerning arsenic toxicity can be measured scientifically, but the present question is how the arsenic-affected patients are living with the context of their illness. The above discussion of the social problems of arsenic-affected people reveals a picture of social hazard faced by affected people. The social loneliness, social injustice, damage of social bonds in the study area make the situation hazardous.

Some people were found to be affected by arsenicosis and have been leading miserable lives. In nearby Kolaroa *Upazila* of Satkhira district, some social problems are prevailing due to arsenic poisoning (The Daily Star: 21/08/2001, Dhaka, Bangladesh). In addition, it has been reported in a national daily newspaper that, frustrated by the treatment of the local doctors, one patient went to India for better treatment, but failing to be cured, she attempted to commit suicide by taking poison (The Daily Star: 04/07/2001, Dhaka, Bangladesh).

In rural areas of Bangladesh, the problem becomes a headache for parents to get their arsenic affected daughters married (WHO, 1996). Arsenic problems already spread into the job market and it is observed closely that qualified candidates called for interview are not offered job. The most devastating situation arises when people die from arsenicosis. Some 'Molla' (local so-called cleric) are not interested to bury them with the Muslim rites and there is no consolation of this death. I found this during my field visits in Marua village of Jessore district in 1999.

There is a very little literature on arsenic and social hazards, but, in view of the qualitative methodological approaches adopted for this study, it can be assumed that people's perceptions about their social conditions caused by arsenic indicate worse social situations than they have ever faced before. This leads to the point that arsenic-affected people are becoming detached from any social activities and these social problems are finally creating social hazards (UNICEF, 2000).

6.7 CONCLUDING REMARKS

The efficacy of qualitative analytical procedures has provided insights into the lay understandings of the arsenic-affected people about their social problems. An attempt has been made to uncover patients' perceptions of their social problems and how they manage their regular lives. In-depth interviews and focus-group discussions were adopted to explore these perceptions. In addition, tubewell holders were also asked relevant questions during the collection of water samples. This chapter has discussed the effects of arsenic on human health, the survival strategies of affected patients in the form of coping strategies and adapting strategies, and the attitude on different levels of people towards the patients.

The chapter has explored the experience of living in a society with arsenicosis. It has been found that this involves living with social uncertainty, social injustice, social isolation and problematic family issues. Qualitative methodological approaches were explored for aptitude and functionality in identifying social issues and these approaches have been demonstrated as an excellent tool to handle a wide range of textual databases in a significant form.

The qualitative data have enabled a complex understanding of how poor arsenic-affected people perceive their social situation and the factors influencing it. In has been found from the study that patients' opinions on their social problems reveal the impact of arsenicosis on their social life. This chapter has also explored the patients' own ideas about their social problems and the social management, i.e. what they think and do in terms of survival strategies and the solutions they envisage.

This chapter has addressed the social situation of people during their illness. The next chapter (chapter VII) will focus on people's insights of the awareness campaign and the roles of different organisations in solving arsenic-related problems in the study area. Qualitative research methods will also be employed for the next chapter in performing a possible mitigation of arsenic and related problems by implementing technological solutions. In addition, it will focus on the awareness campaign as a mitigation option.

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CHAPTER VII

ARSENIC AWARENESS, MITIGATION OPTIONS and FACTS

CHAPTER – VII

ARSENIC AWARENESS: MITIGATION OPTIONS and FACTS

Awareness campaigns are potentially an important aspect to the mitigation of arsenic poisoning in the study area. Since no curative treatment options have yet been found, campaigning about the impact of arsenic poisoning on health and society could be helpful to reduce suffering. How do local people think about the mitigation options of arsenic? The answer reveals people's perceptions mainly based on the experiences they have had with organisations and professionals. Existing arsenic mitigation options and awareness campaigning materials (posters and leaflets) published by different organisations will be examined for their effectiveness. The roles of different government and non-government organisations, local leaders, and elected administrators will also be reviewed.

The chapter is divided into eight sections. The first section looks at the communications prior to my fieldwork that had been made to the people concerning arsenic issues. The second section points out messages concerning arsenic issues that I myself conveyed to the people. Section 7.3 presents people's voices about the suitable awareness-raising policy for arsenic poisoning in the study area. Section 7.4 discloses some mitigation options and their applicability and suitability. Section 7.5 describes the field experience and theoretical pattern of the contributory roles of different organisations and professionals. Section 7.6 presents the natural options for arsenic mitigation other than those concerned with groundwater. Section 7.7 focuses on the policies and politics of arsenic issues. Finally, section 7.8 makes some concluding remarks on the overall analysis.

7.1 COMMUNICATION CONDUCTED PRIOR TO MY FIELD SURVEY

What kinds of communications had been made to the people concerning the arsenic mitigation prior to my fieldwork in the study area? Many NGOs, government organisations, researchers and professionals are working on arsenic issues. However, are they implementing any mitigation options for poor rural people? I found from the in-depth interviews and focus-group discussions that the Department of Public Health Engineering (DPHE) and some NGOs had made a narrowly-focused propagation by putting up a few arsenic related posters in the study area. Some people had seen and got ideas from those posters, but they did not give any importance to arsenic issues at that time. In addition, arsenic related messages were conveyed to the people through different media. These communications were in several formats:

(a) A small number of posters and stickers on arsenic issues were provided by government organisations, NGOs and international agencies in the study area to make people aware of arsenic poisoning (Figure 7.1). The DPHE in particular, with the assistance of local NGOs, displayed this type of poster. This poster campaign did not impinge much on the awareness of the people. This is because they did not have any idea about arsenic and related toxicological issues. Moreover, the campaign itself was not too forceful.

(b) The posters and stickers focussed mainly on the advice not to use red-labelled tubewell water but rather to rely on green-labelled tubewell water for drinking and cooking purposes (Figure 7.2). It is noteworthy that only a few tubewell water samples prior to my field

Figure 7.1: Arsenic awareness campaigning materials.
Sources: NGO Forum, Bangladesh; and www.bamwsp.org

survey were analysed and that no work had yet been done in labelling safe and contaminated tubewells.

Figure 7.2: Message to people for using green-labelled tubewell for all purposes and red-labelled tubewell not for drinking or cooking purposes.
Source: 18DTP, Dhaka, Bangladesh.

(c) The posters and stickers also referred to arsenic-related diseases, especially the extreme level of arsenicosis, such as gangrene, lost fingers etc. People had at that time never seen that type of affected-patient in their vicinity and they therefore ignored the advice on drinking and cooking green-labelled tubewell water.

(d) Some arsenic awareness posters and stickers focussed on the advice that arsenicosis is not a contagious disease (Figure 7.3). Since arsenic poisoning is new in Bangladesh, some rural people consider arsenicosis to be a curse of nature (Hassan, 2000). It is also notable that there is a tendency to neglect arsenic-affected people in

Bangladesh since it is thought that arsenicosis is like leprosy or a contagious disease.

Figure 7.3: Arsenicosis is not a contagious disease nor is it the result of people's fault.
Source: NGO Forum, Dhaka, Bangladesh.

(e) The DPHE has provided twelve deep tubewells for arsenic-free water in the study area. But, what do local people think about this arsenic-free water? They were confused between arsenic and iron. When they found iron concentrations in the water at that deep tubewell then they thought arsenic was similar to iron and most people for this reason were unaware of arsenic.

(f) The government was continuing to conduct its awareness campaign over the radio, television and newspapers. The campaigning procedures were not strong enough to make people aware. Some people told me that they had heard radio announcements about arsenic poisoning and its preventive measures, but a very few people had taken any interest. A few people in the study area have got television and they saw some advertisements on arsenic issues, but again they did not give any importance to it. Most of the people in the study area are illiterate and some of them had seen arsenic-related pictures in newspapers at Ghona *hatkhola*, but they did not know what they meant.

(g) Government awareness campaigns through the media do not make sense to the people of the study area since no patients have been diagnosed and no tubewells were marked with red or green colours. People hear and see announcements, advertisements and posters, but none of these have had any effect on their water-use practice. They continued to use tubewell water for drinking and cooking purposes.

(h) The government, NGOs and many organisations recommend drinking surface water after boiling and cooling it, since surface water is arsenic-free and it will be pathogen-free if boiled. I found that some rural people were boiling their tubewell water before using it for drinking purposes. Ironically, boiling arsenic-contaminated water actually increases the arsenic concentrations.

7.2 ARSENIC AWARENESS MESSAGES

The approaches to an arsenic awareness campaign should emphasise the 'communication process' (Hanchett *et al*, 2000) to the people of the study area. The need for information concerning arsenic poisoning and its mitigation options is an important aspect of any such campaign. People continue to need information and support when there are changes in their health situation due to arsenic poisoning. Arsenicosis neither develops in a day, nor do arsenic-affected patients seek help in a day, and nor does an arsenic-affected person die in a day. Thus, the best possible way is to prevent arsenic poisoning in the first place and the best measure is to make people aware of arsenic poisoning and related diseases.

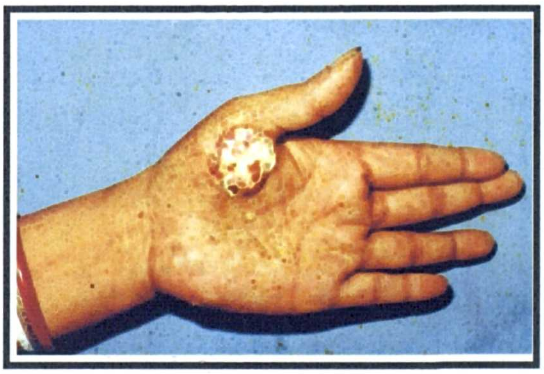
Several types of messages concerning arsenic issues were communicated to people of the study area during my field survey. I advised them that arsenic poisoning might result from continued use of tubewell water for drinking and cooking purposes. Once arsenicosis attacks, there is no curative treatment for it. How do they perceive the messages? Are they interested in changing their water-use habits? Are they panicking? How effective are present communication strategies? It is important to make people aware first about the toxic nature of arsenic because they can then adopt preventive measures until the appearance of a long-term sustainable mitigation option.

(a) **General arsenic concept:** During the collection of water samples from each tubewell in my study area, I told every tubewell holder and the neighbouring people about the water quality of tubewells and the nature of arsenic. I conveyed messages concerning toxicity so that they could have a general idea about arsenic. After the analysis of water samples at Jadavpur University, Kolkata, India, I went to every tubewell a second time and let the tubewell holders and the neighbouring families know about the arsenic concentrations. I also notified them about the impact of arsenic on health and on social issues with reference to my previous experience of other areas that I gathered during my (pre-Durham) consultancy work at the BAMWSP (Bangladesh Arsenic Mitigation and Water Supply Project) funded by the Government of Bangladesh (GoB), the World Bank (WB) and the Swiss Agency for Development and Co-operation (SDC).

(b) **The precautionary principle:** The tubewell holders and neighbouring people were notified that the tubewell is the main source of groundwater arsenic. This is harmful to humans if they ingest an excess through drinking and cooking. The message let them know about the source of arsenic and associated risks. They were also notified that a few years of continued exposure to low levels of arsenic causes different skin lesions, and after a latency period of 20-30 years, internal cancers, particularly in the bladder and lung, can appear. I showed them some photographs of arsenic-affected patients (Figure 7.4) to help them understand the toxic nature of arsenic. At this stage, many people asked me questions about arsenic and I answered in order to make them more aware. I also told people different kinds of social impacts that can affect their social lives.

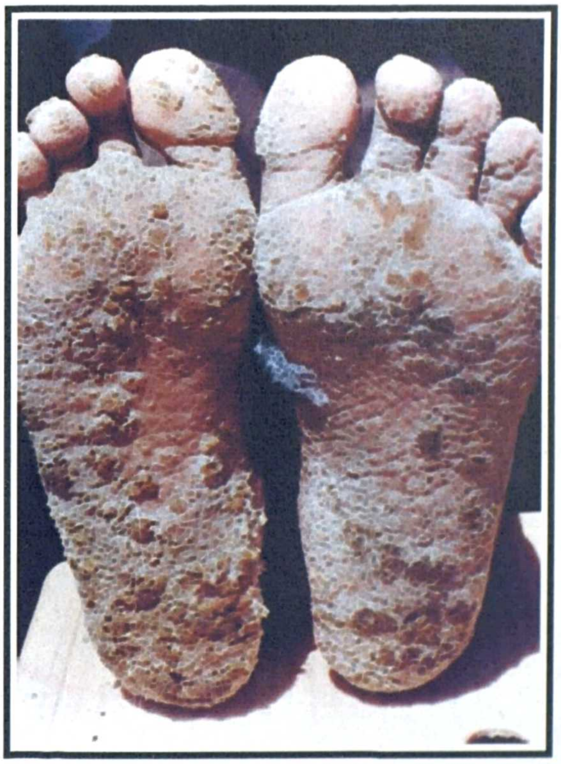
Arsenic lesions on chest
http://angelfire.com/ak/medinet/file5.html

Arsenic lesions on hands, missing finger
http://phys4.harvard.edu/~wilson/arsenic_project_sufferer_picture16.jpg



Arsenic lesions on hand, cancer
http://phys4.harvard.edu/~wilson/arsenic_project_sufferer_picture11.jpg

Arsenic lesions on hands
http://www.nytimes.com/library/world/asia/111098bangladesh-water.htm



Arsenic lesions on feet, extreme
http://phys4.harvard.edu/~wilson/arsenic_project_pictures2.html

Figure 7.4: Pathological manifestations of arsenicosis on human bodies.

(c) **The mitigation principle:** Tubewell holders and local people have been notified about the mitigation options of arsenic poisoning. They have also been informed about the preventive measures and some available low-cost arsenic removal technologies (Box-7.1). Moreover, during the in-depth interviews and focus-group discussions, I posed some questions to help me understand peoples' perceptions regarding arsenic issues and what they think about arsenic awareness and suitable mitigation.

Box 7.1
ARSENIC MITIGATION OPTIONS

Preventive Measures: Several preventive measures and technological options can be used to obtain arsenic-free safe drinking water in rural Bangladesh. The most instantaneous preventive measure is to **share** the untreated tubewell water that is currently free from arsenic. In some contaminated areas no tubewells contain safe levels of arsenic or only a few tubewells are safe. Moreover, tubewells with previously safe test results may later be found to have increased levels of arsenic (WHO, 2000). **Deep tubewell** is another alternative source for arsenic-free groundwater. The BGS found only two tubewells out of 280 below 200 metres in Bangladesh to be contaminated with high levels of arsenic (BGS, 1999) and they advised people to use deep tubewell water until a permanent mitigation option is found. **Rainwater harvesting** is an important source for arsenic-free drinking water (UNICEF, 2000 and WHO, 2000). Rainwater use has proven to be successful elsewhere in Taiwan, Sri Lanka and Thailand. The people of Mongla seaport area in Bangladesh preserve rainwater for their drinking and cooking purposes. **Passive sedimentation** technology is the storage of tubewell water for 12 hours with no chemicals. After storage, the upper two-third of the *kolsi* (jar) can be used and the lower one-third is discarded (Jones, 2000a). It is an effective option but is not a complete solution. In addition, hand-dug wells, and boiling surface water etc could be used as preventive measures.

Low cost Technologies: Apart from the above preventive measures, there are low-cost technologies to be considered. **Bucket treatment** relies on flocculation after the addition of potassium permanganate and aluminium sulphate (alum). This technology results in high percentage reductions of arsenic from tubewell water. Arsenic removal using the bucket treatment method is being tested by the DPHE/DANIDA as a alternative for the transitional period until a 'permanent' solution is found (Jones, 2000b). The **pond sand filter** (PSF) is a slow sand filtration system, which can remove bacteria from water from a nearby clean pond by filtering it through a large tank filled with sand and gravel (UNICEF, 2000 and Chowdhury 2001). It is a community based mitigation approach and can be used successfully in arsenic-affected areas. The NGO Forum has been testing and installing PSF systems for safe water options in many of the affected areas of the country (Haq, 2001b). The **3-kolsi filter** with chemicals can be used to remove arsenic from groundwater. There are other methods of arsenic removal, such as adding iron or aluminium salts to water, or passing water through various kinds of filters, which researchers are currently evaluating (UNICEF, 2000).

During this phase, I informed the respondents and participants about the pattern of arsenic concentrations in the study area. Apart from this, I also tried to let the people know about different mitigation options provided by the GoB, NGOs and many organisations.

(d) **Influencing key actors:** People have been informed about the possible roles and activities of different government and non-government organizations in arsenic issues. In the final phase of my field survey, I distributed a list of safe tubewells (17 tubewells out of 375) and a short guideline about the impact of arsenic, to different people and bodies in the study area (e.g. *imams* of mosques, elected administrators, head teachers of schools, political leaders and social activists). They can now strengthen their arsenic campaigning and awareness raising of the local people based on these guidelines.

7.3 AWARENESS CAMPAIGN: PEOPLES' OPINIONS

What do the local people think about awareness campaigns for arsenic poisoning? Many had the habit of drinking and cooking with surface water until a few decades ago. Recently they have changed their water-use practice to tubewells in order to save them from bacteriological and water-borne diseases. This tubewell water is now contaminated with arsenic. Where will they go now? Which water will they drink now? During personal communications, in-depth interviews and focus-group discussions, a number of opinions emerged on how to make people aware to prevent arsenic poisoning.

What of publishing in newspapers or on television or announcements on radio about the dangerous impact of arsenic on human health? People can understand about the extreme level of danger of arsenic impact on health, but they do not understand about the initial stage of arsenicosis symptoms. One focus-group participant said, ". . . Nobody knows the initial symptoms of arsenic related diseases. It is important to emphasise the initial health symptoms so that people can understand the problems from the very beginning". Many people do not come to know about the impact of arsenic until the symptoms appear in their own bodies. But, there is no treatment if the symptoms are severe, and people therefore panic about arsenic.

7.3.1 Media based information dissemination

In the arsenic awareness campaign, information dissemination concerning the related issues of arsenic through electronic media is important. Some people thought that proper means of communication is vital to prevent arsenic problems. It is necessary to propagate and circulate widely about the toxic effects of arsenic. Most of the poor people in the study area cannot afford radio and television. In addition, daylong electrical interruptions mean that some people do not use any electrical equipment. In a question concerning the current government awareness campaign on arsenic through radio and television, one arsenic-affected respondent replied that:

> ". . . . I do not know anything about the government awareness campaign for arsenic poisoning. I have got a radio, but I cannot afford batteries for it. I earn TK25.00 daily. How can I arrange batteries for my radio? When I go the *hatkhola*, I hear something about arsenic from people, but I don't give any importance to it." [In-depth interview, 2001].

Apart from the economic disadvantage of people and the continuous electrical interruptions, the vast majority of people in the study area are illiterate and cannot read newspapers. Therefore, electronic media in the form of a multimedia projector or the cinema could be utilised for information dissemination. Government organisations, NGOs and different national and international organisations could contribute to this. Some focus-group participants thought that if a cinema film was produced and several shows were arranged in Ghona, poor rural people could gain awareness quickly. Some respondents suggested that several days of announcements about arsenic issues with a loudspeaker or microphone in Ghona could also be helpful, but other participants were less optimistic about this option.

Theatre staging is another interesting and potentially important method for campaigning (Figure 7.5). Almost all focus-group participants agreed that arranging several performances in Ghona *hatkhola* (in Ward 4) and Bharukhali *hatkhola* (in Ward 9) would be effective. In addition, it is possible to make people aware through meetings, seminars, symposia etc. One focus-group participant suggested that a public meeting at Ghona *hatkhola* would assist a quick campaign.

Figure 7.5: A theatre group can improve villagers' awareness.
Sources: [http://www.dpimages.com/arsenic.htm].

7.3.2 Marking tubewell spouts

Marking tubewell spouts with a green or red colour based on arsenic-free or arsenic-contamination has been fundamental in arsenic awareness campaigns in Bangladesh. People are advised to use green-labelled tubewells and to avoid the red-labelled ones for drinking and cooking purposes (Figure 7.6). Some people assume that they must use green-labelled tubewells for their drinking and cooking purposes; while red-labelled tubewells can be used for domestic purposes other than drinking and cooking. One respondent said:

> ". . . . People are getting awareness from radio and TV that all green-marked tubewells are safe and all red-marked tubewells are arsenic contaminated. If people identified the green-labelled tubewells, they will collect water from those tubewells and they will avoid red-labelled tubewells". (In-depth interview, 2001).

The government, NGOs and many national and international organisations are campaigning for the use of green-labelled tubewells rather than red-labelled ones. It has been found that only 2% of the tubewells in Bangladesh have been analysed (The Daily Star, 17/05/02, Bangladesh) and no one knows when the remaining tubewells will be analysed. Based on the results analysed, the tubewells are marked either with red or green labels. The issue is how to let people know about arsenic concentrations in their tubewells where no analysis has yet been done.

Labelling a tubewell spout green — Marking a tubewell spout red

Figure 7.6: Marking the tubewell-spouts green or red.
Sources: [http://www.bamwsp.org].

Some people in the study area assumed that painting the arsenic-free tubewells green would help children not to drink water from red-coloured ones. At the moment, children drink water anytime from any tubewell close to them, but they are more aware about arsenic than their elders and have already learned some ideas about it, as discussed in the next section.

7.3.3 Inclusion of arsenic issues in the school curriculum

Children can easily come to know about arsenic and related issues if it is included in the academic curriculum, just as population problems, floods, cyclones, etc have already been included in different academic curricula for permanent proliferation. Some respondents thought that teachers of schools and *madrashas* (religious schools) could play a role in the arsenic awareness campaign because children listen to their teachers. Whatever a teacher teaches pupils concerning arsenic issue, they will try to follow it, and they may share their knowledge with their parents. If pupils pass on information to illiterate parents and elders, it will benefit the economically disadvantaged section of society.

7.3.4 More information, more awareness

Some focus-group participants said in the discussion that, ". . . It is the responsibility of the government to provide people with information about arsenic and its preventive measures at any cost since it is a national issue." Some focus-group participants commented on my activities in Ghona:

> ". . . . The process you are following in collecting arsenic data, communicating to the rural poor people, and discussing arsenic issues with them and us is a model. If government organisations, NGOs, and policy-makers follow a similar process, people can become aware quickly about arsenic poisoning." (Focus-group discussions, 2001).

Tubewell holders could also play a contributing role in arsenic awareness since they receive more information than ordinary members of the public. Different people and organisations make contact with them regarding drinking water quality and tubewell related issues. After the 2000 flood, DPHE engineers and NGO representatives made contact with them and advised them how to use flood-contaminated tubewell water. They followed their recommendations and advised local people who collected water from their tubewells. This could readily be extended to arsenic.

7.3.5 Arsenic training

The arrangement of short training courses for different working groups in Ghona, for example, health workers, NGO workers, and village doctors would be productive. After receiving training on arsenic issues, they could work in Ghona to make people aware as part of their job. Some focus-group participants insisted that the trainees must be the people of Ghona and, after completing their training, they should work in Ghona and participate in local arsenic issues.

Most respondents and participants preferred health workers rather than NGO workers for arsenic training. This was because the health workers are well-known to rural poor people and in recent years they have played a contributory role in reducing diarrhoea, and have organised family-planning activities, and national schemes for immunisation against polio and so on. If the government could arrange training for local health workers, they could subsequently contribute to the arsenic awareness campaign as well as to arsenic preventive measures.

7.3.6 Participation of educated people, *imams* and leaders

Local educated people, school-*madrasha* teachers, college teachers, *imams* of mosques, local leaders and social activists could also contribute. Teachers could alert poor people living close to them about arsenic poisoning and its preventive measures until the government is able to take strong mitigation action. One focus-group participant said that if teachers took arsenic related posters and leaflets to local poor and illiterate people, they would be taken seriously since the rural people treat teachers with respect.

Imams of mosques are also in a position to advise people to take arsenic preventive measures during prayer times. In addition, they could let people know which tubewells are mainly safe. During the finishing stages of my field survey, I provided lists of safe tubewells to some *imams* in the study area. People always respect their imams as clerics and if the *imams* tell people about arsenic issues and show people different photographs of arsenic-affected patients, this would encourage the adoption of different preventive measures.

Local leaders and social activists could arrange for the labelling of contaminated and safe tubewells on the basis of the safe tubewell list provided to them by this author. Moreover, they could advise their people to use green-labelled tubewells in place of red-labelled tubewells. They could also give them advice to boil pond water for drinking and cooking purposes, as they used to do decades ago.

7.4 WHICH MITIGATION OPTIONS?

There is a general lack of awareness surrounding health issues in the study area. Some of the recent health problems caused by arsenic poisoning have a low priority to many rural poor people, and they see the issues surrounding health and illness as 'non-threatening' (Gibbon, 2000). In the study area, people were continuously using contaminated tubewell water and they were ignoring arsenic poisoning. Since it is a question of life and death and affects future generations, all concerned national arsenic mitigation guidelines should be appropriate and effective.

During the course of my field survey, I told people about the impact of arsenic on health and showed them some arsenic-affected patients' photographs (Figure 7.4). Some of them then decided to accept some mitigation options proposed by government organisations, NGOs and researchers. This section will focus on several of the preventive measures and technological options that could be used to provide arsenic-free safe drinking water in rural Bangladesh. There are several methods that have been applied but these have not reached the people. Several of the methods are inadequate and expensive and some are low-cost. The BAMWSP has approved both the surface water and chemical options for mitigation purposes (The Daily Star: 06/07/01, Bangladesh). The BAMWSP has recommended four non-chemical based technological options for a short-term mitigation programme: (a) Pond Sand Filter (PSF); (b) Deep tubewell; (c) Rainwater harvesting; and (d) Dug-well (http://www.bamwsp.org). The choice between these options should take into account their cost-effectiveness in providing arsenic-free and microbiologically safe drinking water.

7.4.1 Sharing existing arsenic-free tubewells

When a family finds that their tubewell is arsenic-contaminated, the fastest and easiest way to obtain safe drinking water is to find a nearby tubewell that has been tested for arsenic and found to be safe (UNICEF, 2000). From the field survey, it has been found that almost all of the tubewells are contaminated and that very few tubewells produced water that was safe to drink. Therefore, it is envisaged that the community can share these safe tubewells located within very short distances in a *para* (a cluster form of rural community) for drinking and cooking purposes (Figure 7.7).

During the field survey, people were advised to collect water from arsenic-free tubewells and the owners of safe tubewells were encouraged to share their tubewells with their neighbours. Some people decided to continue the collection of water from arsenic-free tubewells. Others were adamant that they wanted to collect water from arsenic-free tubewells provided by the government rather than private tubewells. They pointed out some problems created by tubewell-holders during the collection of water from their tubewells.

Figure 7.7: Sharing the existing arsenic-free safe tubewells as a preventive measure to reduce arsenic poisoning.
Source: Field Survey, 2001.

During the course of informal discussions and interviews with poor people, I found that some tubewell-holders were felt to behave negatively and rudely towards those collecting water from their tubewells. One respondent installed a tubewell in 1998 to avoid harrassment from a neighbouring tubewell-owner and when I told him that this new tubewell was contaminated with arsenic, and not to use it for drinking and cooking purposes, he replied that: ". . . I know this water is better than other tubewells in this area and I will drink this water, I will not go to another tubewell to collect water. It is an embarrassing situation to collect water from the neighbouring tubewell. I have had bitter experiences in collecting water from different tubewells."

Some tubewell-holders gave a negative response to this type of allegation. They said that any problems were due to misunderstandings with the poor and that people still have access to their tubewells for collecting water. Some tubewell-holders are not happy with poor people claiming that they frequently damage their tubewells, create noisy conditions all day and make the tubewell platform dirty. Some were said to allow dust into the tubewells. When these situations happen, the tubewell-holders become angry with poor people, but only one case has been identified where the tubewell-holder did not allow people to collect water from his tubewell. One respondent on this issue told me that:

> ". . . . My tubewell is contaminated with arsenic and people come to my tubewell everyday and collect water from it. I do not tell them not to collect water from my tubewell until alternative sources are available, because if I tell them not to drink this tubewell water, they will be angry with me, or they could think I'm not allowing them to collect water from my tubewell." (In-depth interview, 2001).

The participants of one focus-group agreed that some tubewell-holders do have problems with those collecting water from their tubewells and that quarrelsome situations arise during the collection of water. One participant who has already got one deep tubewell told me that he is bored with living in such noisy conditions. He wanted to install another deep tubewell in his courtyard to avoid such irritating situations.

7.4.2 Dug-wells

The BAMWSP has recommended using hand-dug wells as a non-chemical based short-term mitigation option (www.bamwsp.org) and people in highly arsenic-contaminated areas can use water from dug-wells (Figure 7.8). These are shallow hand-excavated wells and are the traditional source of water. The water from such wells is arsenic-free and it does not contain harmful chemicals and/or bacteria (UNICEF, 2000); also, iron concentrations are quite low in dug-wells (Chakraborti, 2001). Dug-wells are safe with respect to arsenic contamination compared to hand-pump tubewells. It has been found that about 84% of dug-wells are arsenic-free by the WHO permissible limit and 99% are within the Bangladesh standard permissible limit (Chakraborti, 2001). One hand-pump tubewell contained 1.390 mg/l of arsenic, whereas a dug-well located only 10 metres away from that hand-pump tubewell had only <0.003 mg/l of arsenic (Chakraborti, 2001).

Before the hand-pump tubewell culture started decades ago, rural people were mostly dependent on dug-wells. They drank dug-well water and this water was suitable at that time. Dug-wells are now being re-introduced as a source of arsenic-free water (UNICEF, 2000). Dug-wells can be used for drinking and cooking purposes after assessing the water quality (Alaerts *et al*, 2001).

Collection of water directly   Water collection through tubewell

Figure 7.8: Dug-wells are the source of arsenic-free water.
Sources: [www.dpimages.com/arsenic.htm] and [www.bamwsp.org].

Since after the green revolution in the study area from the 1980s, huge groundwater extraction from machine-pumped deep tubewells for agricultural purposes has lowered the groundwater aquifer level. This impacts on shallow aquifers and on the dug-wells in Bangladesh. I found from the field survey that during the dry months, there was no water at all available in shallow tubewells and in dug-wells.

People can use dug-well water during the rainy season, but problems arise during the dry months. The important issue remains of how to make safe drinking water available during the dry months in the study area. A very little water is available in a few tubewells in the study area; while most of the tubewells do not have any. People of the study area confirmed that if water were available in the dug-wells, they would use that water to save themselves from arsenic poisoning.

7.4.3 Rainwater harvesting

Rainwater harvesting is an important source of arsenic-free drinking water. Both the BAMWSP and the UNICEF have recommended rainwater harvesting to avoid arsenic poisoning. It is a recognised and successful water technology in use in many developing countries around the world including China, Sri Lanka and Thailand. Properly stored rainwater is safe from bacteria, and can be stored for many months (WHO, 2000). Research by the ICDDRB (International Centre for Diarrhoeal Disease Research in Bangladesh) confirms that rainwater can be a safe drinking water source (UNICEF, 2000).

This system has been used in coastal districts of Bangladesh for years, and is being introduced in arsenic-affected areas. People of the southern districts under Barisal division have been storing rainwater for their drinking purposes (Figure 7.9). Rainwater harvesting plants have already become popular among the people of the coastal districts due to health-related concerns over tubewell water (The Daily Star: 17/06/2001, Bangladesh). The NGO forum first started a rainwater harvesting plant in Patuakhali district in 1999, and now about 190 such plants have been set up there and many families are getting pure drinking water (The Daily Star: 17/06/2001, Bangladesh). The NGO forum plans to set up more rainwater harvesting plants, but DANIDA and the DPHE have tried to install tubewells (The Daily Star: 17/06/2001, Bangladesh).

Rainwater from sheet rooftop   Community rainwater harvesting   Preservation of rainwater

Figure 7.9: Rainwater harvesting and preservation is a preventive measure for arsenic poisoning.
Source: UNICEF, 2000 and http://www.bamwsp.org.

Rainwater is collected using either a sheet material rooftop and guttering or a plastic sheet with the water being diverted to a storage container (WHO, 2000 and UNICEF, 2000). Users let the first few minutes of rainfall run off without collecting the water, to clean the roof and gutters. People can use rainwater for drinking and cooking through the dry season.

Since Bangladesh has a monsoon climate, people can preserve rainwater during the rainy season (June to September) for the dry months. This is a relatively low-cost mitigation option. Some of the respondents gave positive views on the use of rainwater, but mentioned that they need technological help, while other participants rejected this measure because of financial constraints. During the field survey, the question was raised of how to harvest and preserve rainwater by the rural poor since most of their houses have straw rooftops (Figure 7.10).

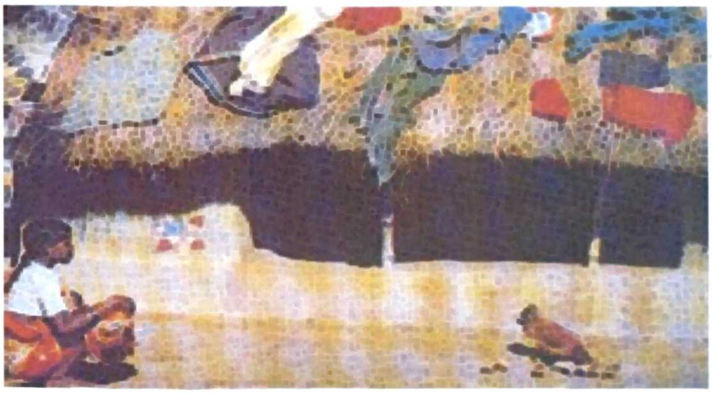


Figure 7.10: How suitable is this roof for rainwater harvesting.
Sources: [http://www.dpimages.com/arsenic.htm].

7.4.4 Use of surface water: Digging ponds or reservoirs

During the course of my field survey, I conveyed a proposed arsenic mitigation option by the LGRD minister of Bangladesh to local people. The previous Local Government, Rural development and Cooperatives (LGRDC) minister of the Awami Government in a National Conference on "Coordinated Action for Arsenic Mitigation Programme" which was co-organised by the Government of Bangladesh and UN Agencies on 27-28 February 1999 said that the government would resolve arsenic poisoning within ten years by digging at least one pond in every *union* for arsenic-free drinking water in arsenic affected areas (The Daily Star: 22/09/1999, Bangladesh).

The field survey showed that local people were wary about this government policy. They thought the proposal to be untrustworthy and to have sinister motives. They asked how the government will resolve the problem within ten years, when arsenic concentrations are increasing rapidly. If the government implements its plan, it will need to renovate the ponds each year, otherwise the banks will be broken during the rainy season and dirty water will enter the ponds. Pond water is not pathogen-free and use of this water for drinking can lead to different types of water-borne diseases (Figure 7.11). Participant said:

> ". . . . What will be the benefit of this plan? This is not a constructive policy proposed by the government. Water in that pond would be polluted with a lot of garbage that will enter into the pond during the rainy season, and then who will drink this arsenic-free water?" (Focus-group discussion, 2001).

Moreover, one respondent said:

> ". . . . How can the government propose this type of plan for arsenic-free water? Germs could contaminate pond water. Children can misuse this water, farmers can wash their cattle into the pond, and people can take a bath or can wash clothes and so on. How safe is this water for cooking and drinking?" (In-depth interviews, 2001).

Which ponds could be excavated or which tanks could be used as reservoirs for arsenic-free drinking water? Many government owned ponds, tanks, and canals are occupied illegally and the government plans to free these water bodies from unauthorised possession for its planned development to benefit the poor people and conserve nature (The Daily Star: 12/11/01, Bangladesh).

Washing dishes and swimming in a community pond. This multi-usage has made pond water unsafe to drink

Water collection from a pond to purify

Figure 7.11: Uses of pond water by the villagers.
Source: [http://www.dpimages.com/arsenic.htm]

Most people are not interested in using pond water – they prefer deep tubewells to any of the alternative mitigation options. Moreover, people think that a deep tubewell is more economical than digging and managing a pond. Some focus-group participants estimated that ". . . to dig a medium-sized pond would cost TK75,000 (£1000.00) and need more money each year for taking care of the pond. Within this budgetary provision, it is possible to install 2-3 deep tubewells in Ghona and people could continue in their habitual exercise of drinking arsenic-free water from deep tubewells."

7.4.5 Use of deep tubewell water

People have come to know from many sources that arsenic-free safe drinking water is available from deep tubewells. They abandoned their pond water practices about three decades ago and they are now fully dependent on tubewell water rather than other sources of water. Many are not motivated to take any preventive measures except the deep tubewells and they want to confine themselves to deep tubewell water (Figure 7.12). One respondent told me that:

> ". . . . I have come to know from some training that tubewells installed at a depth between 100-150 feet are concentrated with high levels of arsenic; while concentrations are very low in deep tubewells. I have been using water from a deep tubewell of Ghona *Hatkhola* from the time when I came to know that tubewells of this area are contaminated with arsenic. Some people of this area are collecting water from deep tubewells. I do not use my own tubewell water and do not allow others." (In-depth interview, 2001).

It is true that the deep aquifer is much less contaminated than the shallow one. A hydrogeological study conducted by the British Geological Survey tested 280 tubewells deeper than 200 metres, and found only two contaminated with arsenic (BGS, 1999). The DPHE has also tested many deep tubewells, and found only limited arsenic contamination (UNICEF, 2000). Use of deep tubewells has been suggested as a safe option in the face of arsenic contamination of groundwater in a report undertaken by the DPHE with financial assistance from the JICA (Japan International Cooperation Agency) (The Daily Star: 08/08/2001, Bangladesh). They made the recommendation to sink deep tubewells in other affected areas with proper tests.

The people I spoke to assumed that it is the responsibility of the government to help poor people. If the government installed deep tubewells for arsenic-free and safe water, there would be no arsenic problems as well as might not water-borne diseases like cholera and diarrhoea. Since most people in the study area cannot afford a deep tubewell, it would be necessary to install deep tubewells in suitable locations with the help of government funds.

People are anxious to collect water from a deep tubewell

Multi-use of a DPHE provided deep tubewell

Figure 7.12: Water collection from a deep tubewell and the use of deep tubewell for bathing.
Source: Field survey, 2001.

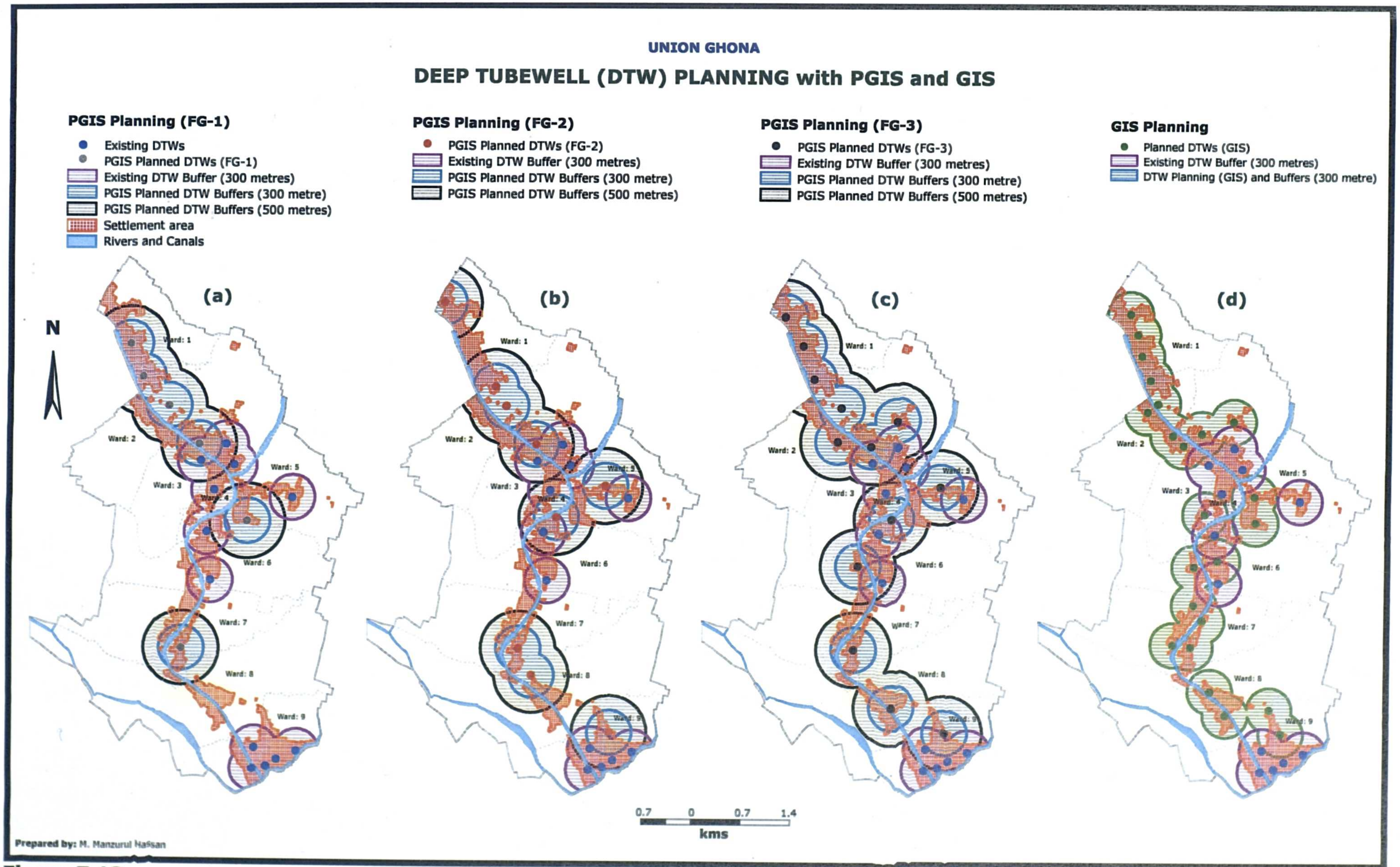
In the opinion of villagers, there should be a government policy and plan to provide a deep tubewell for every 40-50 households free of cost. If this happens, it will be possible to save rural poor people from arsenic poisoning. Moreover, people thought that for its long-run safety and management, it is better to provide a deep tubewell under a caretaker to prevent misuse.

PGIS planning for deep tubewell: What are the suitable sites for installing additional deep tubewells in the study area for a mitigation option? How many deep tubewells will be needed and what are the basis of it? Many focus-group participants pointed out different possible sites for additional deep tubewells for obtaining arsenic-free water. People's perceptions on this issue are mainly focussed on the 'threshold distance' (the distance people could travel maximum for collecting arsenic-free water from a deep tubewell); while others explained their comments related to the population size, number of households and sometimes the area of the neighbourhood. Some participants considered different schools and *madrashas* as the suitable areas to install deep tubewells. Generally, people thought that the threshold distance covers half a kilometre buffer distance for a deep tubewell.

Based on the threshold distance, participants of a focus-group (FG-1) outlined their views on planning for installing deep tubewells. They commented that if deep tubewells are installed within a short distance, people could collect water conveniently. They assumed that people could collect deep tubewell water within half a kilometre walking distance and, based on this opinion, they pointed out that six additional hand-pump deep tubewells could fulfil the demand of arsenic-free water for the study area. They suggested two deep tubewells for Ward 2; one each for Wards 1, 3, 5 and 7; and no deep tubewells would to be needed in Wards 4, 6, 8 and 9 (Table 7.1 and Figure 7.13). Only 12 deep tubewells exist in the study area at present.

Participants of focus-group 2 outlined suitable areas for deep tubewells based on the location of schools and *madrashas*. They identified nine points for installing deep tubewells, which cover eight schools and one *madrasha* and these additional deep tubewells could cover the unserved zones of the study area. This selection also covered the threshold distance. They thought that about 400 pupils attend a school on an average basis, and a school is open for 6-7 hours in a day and it is not possible to stop them drinking tubewell water since there is no alternative. Therefore, it is better to install deep tubewells in schools.

Schools are mainly located in the densely populated areas so people can easily get access to deep tubewells. According to their opinion, two deep tubewells should go to Wards 2 and 5 each; one should go in Wards 1, 3, 7, 8 and 9 each; while no deep tubewells will be required for Wards 4 and 6 (Table 7.1 and Figure 7.13). They also thought that the government should take positive action to install deep tubewells to save children and people in the study area from arsenic poisoning in place of the development of roads and infrastructure for a year.


UNION GHONA
DEEP TUBEWELL (DTW) PLANNING with PGIS and GIS
PGIS Planning (FG-1)
Existing DTWs
PGIS Planned DTWs (FG-1)
Existing DTW Buffer (300 metres)
PGIS Planned DTW Buffers (300 metre)
PGIS Planned DTW Buffers (500 metres)
Settlement area
Rivers and Canals
PGIS Planning (FG-2)
PGIS Planned DTWs (FG-2)
Existing DTW Buffer (300 metres)
PGIS Planned DTW Buffers (300 metre)
PGIS Planned DTW Buffers (500 metres)
PGIS Planning (FG-3)
PGIS Planned DTWs (FG-3)
Existing DTW Buffer (300 metres)
PGIS Planned DTW Buffers (300 metre)
PGIS Planned DTW Buffers (500 metres)
GIS Planning
Planned DTWs (GIS)
Existing DTW Buffer (300 metres)
DTW Planning (GIS) and Buffers (300 metre)
(a)
(b)
(c)
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N
Ward: 1
Ward: 2
Ward: 3
Ward: 5
Ward: 6
Ward: 7
Ward: 8
Ward: 9
0.7 0 0.7 1.4
kms
Prepared by: M. Manzurul Hassan

Figure 7.13

Participants of focus-group 3 considered the schools and mosques to be suitable locations for installing deep tubewells. A few participants though raised the question that if deep tubewells are installed in mosques, women might hesitate to collect water from those deep tubewells. In their selection strategy for suitable places for the deep tubewells, the participants considered population volume and threshold distance. They considered a deep tubewell within the buffer distance of half a kilometre and 500 people. In view of their opinions, thirteen additional deep tubewells would be required for arsenic-free water in the study area, of which three deep tubewells would go to Ward 2; two deep tubewells for Wards 1, 3 and 5 each; one deep tubewell for Wards 6, 7, 8 and 9 each; while no deep tubewell would be required for Ward-4 (Table 7.1 and Figure 7.11).

Table 7.1
Deep tubewell installation planning in view of PGIS and GIS

Wards	Deep tubewell installation planning				
	Existing DTWs	**Focus group 1**	**Focus group 2**	**Focus group 3**	**GIS Planning**
WD-1	-	1	1	2	3
WD-2	-	2	2	3	4
WD-3	1	1	1	2	3
WD-4	3	-	-	-	1
WD-5	1	1	2	2	2
WD-6	2	-	-	1	2
WD-7	-	1	1	1	4
WD-8	1	-	1	1	3
WD-9	4	-	1	1	1
Required	-	6	9	13	23

Data Source: Field Survey, 2001.

GIS planning for deep tubewell. For GIS planning, I used the threshold population of each administrative ward. The buffer distance of each deep tubewell has been measured from the field survey, considering the population size. It has been found from the fieldwork that more than 350 users for a deep tubewell could generate chaos and overcrowding at the deep tubewell platform during collecting water. Therefore, to avoid this chaos and overcrowding, I based my plan one deep tubewell for each 350 people, generally who live within a buffer distance of 300 metres. Therefore, for about 8000 unserved population, an additional 23 deep tubewells are needed with a buffer distance of 300 metres for each deep tubewell (Table 7.1). Four deep tubewells are required for Wards 2 and 7 each; three deep tubewells for Wards 1, 3 and 8 each; two deep tubewells for Wards 5 and 6 each; while Wards 4 and 9 will require one deep tubewell each (Figure 7.13).

In view of the PGIS planning proposals, it can be seen that there are some overlapping and some unserved areas. Using the 500 metre buffer, some unserved areas are found in Wards 1, 3, 7 and 8; while overlap areas are mainly focussed in Wards 4 and 5 (Figure 7.13). On the other hand, a very few scattered unserved settlement areas result from the scenario based on GIS planning (Figure 7.13).

7.4.6 Boiling surface water

Boiled surface water is an important potential source of arsenic-free drinking water. It has been found from the field survey that people have wrongly assumed that boiling tubewell water can remove arsenic from it. This boiling concept is justified for producing pathogen-free surface water, but is not suitable for removing arsenic from tubewell water. As mentioned before, boiling arsenic-contaminated groundwater actually leads to an increase of arsenic in that boiled water. Some respondents and participants showed a willingness to drink boiled water, but most people in Ghona are small farmers or agricultural labourers and they cannot afford firewood for boiling surface water. They are mainly interested in using deep tubewells for their arsenic-free water. As one poor respondent said, ". . . It is not a good decision to advise people to use pond water to boil; it is better to provide deep tubewells in each neighbourhood." Another respondent in this connection confirmed that, ". . . It is not possible to arrange firewood for boiling pond water. I do not have enough money to arrange food regularly and I cannot buy firewood for water. I will continue to drink tubewell water. If you provide me with a deep tubewell, then I will collect water from that tubewell."

7.4.7 Reflexive sedimentation

A very simple traditional technique for arsenic mitigation is to "*pani basi kore khaoa*" which means "to drink water after letting it settle overnight" (Alaerts *et al*, 2001). This technique can be called "reflexive sedimentation" technology, which is the storage of tubewell water for prolonged periods with no chemicals. The upper two-thirds of a jar can be used and the lower one-third is discarded after storage of the water for over 12 hours (Jones, 2000a). If arsenic contaminated water is stored for over 12 hours, it has been observed that the arsenic concentrations are reduced in the top layers. It is an effective option but is not a complete solution.

In the study area, almost all of the tubewells contain a remarkable amount of iron concentrations. If water is left overnight, it becomes viscous and turns yellowish and the water loses its original taste. So, this "reflexive sedimentation" to settle arsenic, yields tasteless and smelly water. People are actually worried by the iron in some cases. They do not like to use this technique.

7.4.8 Low-cost technology

There are several low-cost technological options for removing arsenic from the groundwater. Water filtrations with the three-pitcher (3-kolsi) system, PSF, water-purification tablets, bucket treatments, Safi filter, alcan[1], garnet, steven[2] etc, are all examples of such technologies. Generally, most people in the study area cannot afford any of these systems. During the awareness campaign

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[1] The alcan technology is based on aluminium. But, the use of aluminium is a grave health concern. A positive statistical link has been found between high aluminium in drinking water and Alzheimer disease (Brown, 1989 in http://www.sos-arsenic.com). Aluminium concentrations in all surface waters in Bangladesh greatly exceed that of WHO (1994) drinking water standards (200µg/l). The normal water of Bangladesh is high in aluminium and after treatment with activated aluminium the aluminium content will rise dramatically, replacing one poison with an other (Anwar, 2001a).

[2] The steven technology for Arsenic Removal is based on coagulation and filtration, where they add iron salt (iron sulphate or iron chloride) as a coagulator with an oxidising agent bleaching powder (Anwar, 2001a).

concerning the use of filtering and water-purification tablets, one respondent asked me, ". . . Who will do this and who will provide me the cost of filter and tablets? I cannot afford any water-purification tablets. I will not drink pond water at all – it is full of germs, dirt and is unhygienic." On the other hand, I was told that during the recent flood, the army provided drinking water to local people purified from a machine. People can adapt to any mitigation option if is cost-free and if the government were to provide this type of machine in Ghona, people could easily access arsenic-free water.

7.4.9 Piped water systems

Many towns and cities have arsenic-free piped water systems. The Satkhira Municipality has the arsenic-free piped water system. Two water-lifting pumps, two overhead tanks and two water treatment plants cover the whole municipality. Although it sounds ambitious, if the government makes a policy to set up one new pump and treatment plant in each *Union*, it could cover the water demands of Ghona.

The recent arsenic-free supply water system in Satkhira Municipality is designed by Dutch Aid. This supply is not fully arsenic-free – an amount slightly higher than the DoE standard (0.053 mg/l) was found in it. Moreover, day by day arsenic sludge is being disposed of in a nearby canal (*Pranshire Khal*) without any treatment (Field survey, 2001). This disposal of highly toxic arsenic sludge to the *Pranshire Khal* could contaminate nearby waterways and surrounding areas. Thus, the arsenic problem in Satkhira Municipality can be tackled in a better way by the alternative option of treated surface water supply rather than by treating groundwater.

7.5 FIELD EXPERIENCE and THEORETICAL CONCEPTS

During my field survey, I have found various organisations to be active on arsenic issues to different extents. The DPHE, NGOs, local leaders, and local elected administrators were all working to resolve arsenic-related problems. People's opinions about their activities reveal the real situation in combating arsenic poisoning in the study area.

7.5.1 NGO activities

NGOs could play a positive role in arsenic mitigation action. They get legal authority from the government to conduct "socio-economic development" for rural poor people. Under this agreement, they play a contributory role in arsenic mitigation. They could provide deep tubewells and low-cost household or community-based arsenic removal technologies to their association members through their micro-credit programme. Some NGOs have been trying to provide pure drinking water to the affected people through their different programmes. However, the efforts are inadequate against the requirements (UNB/NFB: 05/06/2001, Bangladesh).

NGOs like the BRAC, the PROSHIKA, the Gramin Bank, and the NGO Forum etc are working on arsenic mitigation policy. Some NGOs analyse arsenic concentrations in tubewell water and they paint tubewells red or green to let people know about arsenic poisoning. NGOs in some places have sealed all of the tubewells and have advised people to find alternative sources of drinking water (Haq, 2001b). Moreover, to carry out arsenic tests in some places, NGOs demand TK100-200 (£1.25-2.50) which many poor people cannot afford (Anwar, 2001b). In the neighbouring *Upazila* (Debhata) to the study area, for instance, NGOs have painted the tubewells red but they did not provide any solutions. Therefore, where do the people find an alternative source?

The NGO Forum is presently working on 'Drinking Water Supply and Sanitation' (DWSS) and they are providing funds and technical assistance for rainwater harvesting systems for arsenic mitigation (Haq, 2001b). Many NGOs are allegedly using arsenicosis patients for their own interests. They collect samples of tubewell-water and biomarker samples (e.g. blood, hair, urine and nail) from arsenicosis patients without mentioning the purpose. They took photographs of the victims. The NGOs, while taking samples, promise to the victims that they will notify them the test results, but it has never done (Haq, 2000). NGOs collect money from donor agencies for testing samples and using victims in the name of so-called laboratory tests (Haq, 2000).

People in the study area expect that NGOs should do something for arsenic affected people. NGOs have grassroots links to poor people – their workers work at the field level and they are well known. One respondent told me, ". . . if the NGOs decide to resolve arsenic problems in this area, they can easily do it, but they will not do. Their main target is to earn more profits from poor women". They provide micro-credit to very poor and illiterate women. After providing them with credit, NGO workers are reported to go to those women's doorsteps once a week or several times in a week to collect instalments of the credit provided by NGOs at an annual interest rate of 69%. Some focus-group participants commented that:

> ". . . NGO workers always go to the doorstep of the poor people. The rural people know them and if they alert people about arsenic, they will respond. If NGOs can do this along with their micro-credit programme, people will quickly be aware about arsenic poisoning." (Focus-group discussion, 2001).

However, most of my male respondents in the study area criticised NGO activities in their vicinity.

> ". . . . What can an NGO do for people in arsenic issue? Where people are in pain from arsenic poisoning, NGOs are not paying any attention in this regard, and they will not do anything to remove people's pain until they think that the business is profitable. They will not resolve any problem permanently and will create another problem to continue their business. They are exploiting poor women by providing them with credit at high rates of interest." (Focus-group discussion, 2001).

Some focus-group participants pointed out about the policy of NGOs and their (NGOs) breaking of commitments to the poor people.

> ". . . . An NGO can do everything in arsenic mitigation, but they will not do anything, they will give you only commitments and assurances. They request poor women to join their association (*samity*) with a commitment that they will give those women benefits. When women join their associations, then they refuse all of their commitments except for their credit facilities." (Focus-group discussion, 2001).

They could play a role in arsenic mitigation, if the process is profit-oriented. One BRAC officer explained their role in providing tubewells in the study area, but there are only two NGO-provided tubewells out of 375 found in the study area. In a question concerning their role in arsenic mitigation, one local NGO officer told me that, ". . . We cannot do anything for arsenic mitigation. We always implement the orders of our higher officials." Another NGO officer said that ". . . We can provide tubewells, but it must go through our micro-credit programme. We can give credit for the cost of a deep tubewell." It is interesting that the local BRAC branch has offered to provide credit for half of the total cost for a deep tubewell if the community are interested. But, people are not interested in taking this credit because they are concerned about potential NGO exploitation.

Locally, people are not happy with NGOs activities[3]. They emphasise the negative activities of NGOs. They thought that NGOs are doing business in the name of "socio-economic development." I found some NGO victims in the study area who once got credit from NGOs and who failed to pay the instalments in time. During one conversation, I discovered one poor woman who took credit from an NGO and when she failed to pay instalments completely, NGO workers then forced her to sell her property. She is now working as a maidservant. There has recently been a story in a national daily newspaper that BRAC employees looted properties from one of their association members since she failed to provide an instalment within the given time. This is said to have happened in Gangadaspur village of Zibbannagar under Chuadanga district (The Daily Ittefaq, 16/11/2002, Bangladesh).

Almost of all the people in the study area criticised NGOs for continuing to exploit poor women in their village. They collect instalments for the credit of TK5000. They actually provide each woman member of an association TK4200 in

[3] Because of the nature of the fieldwork in Bangladesh, the majority of my respondents were adult males. Their responses may be biased by their distaste for the independence which credit gives to women and by their fear of the changing power balance, which may result.

place of TK5000 - they left TK800 for security money. If any member fails to pay their instalments in time, NGO workers then pressurise the other members of that association to arrange instalments from the defaulter. In most cases, when women fail to pay instalments, they make these defaulters poorer and socially isolated. In a question concerning their activities and people's attitudes to them, one NGO officer told me angrily that:

> ". . . . What can we do about the problems? If we tell the poor women about any constructive works for their socio-economic development, they expect everything free. In this situation, it is not possible to do any constructive work." (Focus-group discussion, 2001).

Men are angry with NGO activities since they found changes in their wives' behavioural patterns towards them. In addition, some thought that NGOs interfere in their family structure. One focus-group participant said in this regard that, ". . . It is a safe policy to exploit poor and illiterate women and it is their business. They never give any credit to a man even if he is poor or illiterate. They mainly interfere in our family structure and social structure also."

NGOs were said to work in analysing tubewell water in Debhata *Upazila* and in marking tubewell spouts with red or green colour. Respondents hoped for the same work from local NGOs, but thought that money-making activity is the main business of NGOs and that they know nothing except money. One focus-group participant told me stridently:

> ". . . . Actually, the main objective of NGO activities is the development of the socio-economic conditions of rural poor people, but the reality is different. They will not provide us with anything except high-interest credit. NGOs now mean credit programmes and this is their prime business. They are continuing all of their money-making activities under the banner of socio-economic development." (Focus-Group discussion, 2001).

The general opinion found from the field survey is that in most cases NGOs make rural people poorer, although people also believed that they could develop socio-economic conditions of poor people if they honestly wanted to. One respondent in this connection said that, ". . . I have been hearing from NGOs from my childhood that we will do this, we will do that etc, but they do not do anything except provide credit with high interest. They exploit poor women."

7.5.2 DPHE activities

The DPHE has a contributing role in mitigating arsenic poisoning. The DPHE has been instrumental in a number of large and small-scale arsenic initiatives. These include arsenic analysis in tubewells; mapping the extent of arsenic contamination; testing arsenic removal technologies and alternative options; implementing mitigation measures, and so on (Box-7.2). The DPHE were the first to uncover groundwater arsenic contamination in Bangladesh and they are now playing a contributory role in providing deep tubewells for arsenic-free water. They have already provided twelve deep tubewells in the study area and for each additional one they collect TK5000 from the people as a contribution to costs. The previous Chairman of Ghona Union arranged seven deep tubewells from the DPHE and installed them properly in 1998.

Box 7.2
DPHE ACTIVITIES *in* ARSENIC MITIGATION

The DPHE is one of the key department under the ministry of Local Government and Rural Development (LGRD). The DPHE has a number of different arsenic activities at various levels of implementation and is working with a wide variety of development organisations.

BAMWSP: This is the national co-ordinating project for arsenic issues relating to water supply funded by the Government of Bangladesh (GoB), the World Bank (WB) and the Swiss Agency for Development and Co-operation (SDC). The BAMWSP aims to co-ordinate arsenic interventions through its National Arsenic Mitigation Information Centre (NAMIC) to collect, collate and disseminate arsenic information. The project was formally launched in September 1998 for a period of four years. Included in the mandate of BAMWSP is the emergency activity of screening all tubewells in Bangladesh, testing various arsenic removal technologies and alternative drinking water sources for arsenic mitigation.

DPHE/UNICEF: The DPHE/UNICEF arsenic mitigation initiative to date has consisted of several National-scale activities and a focussed 'Action Research' project in five *upazillas* with the testing of 51,000 tubewells in 1998 using field test kits to give the first idea of the scale of contamination. The 'Action Research into Community Based Arsenic Mitigation' project followed an integrated approach and included four main activities: communication about arsenic and arsenicosis; testing of tubewells; arsenicosis patient identification/support/implementation; monitoring and evaluation of alternative water supply technologies. The technologies tested ranged from home-based solutions (3-kolshi arsenic removal filter) to community-based solutions (PSF for surface water treatment).

DPHE/WHO: The WHO has supported the Government of Bangladesh since the early stages of recognition of the arsenic problem, mostly by providing technical expertise. The WHO has been an active partner to Government and in the context of arsenic mitigation has been involved in an informal Emergency Arsenic Taskforce which has documented an emergency action approach and in GIS mapping of arsenic hotspot villages and working areas of various arsenic projects.

DPHE/DANIDA: Danida has conducted a research in Noakhali in Bangladesh since November 1998 on the removal of arsenic. DANIDA is also providing support in arsenic removal through bucket technologies (Danida, 2000).

Most people in the study area are not happy with recent DPHE activities concerning deep tubewells. In some cases the DPHE has collected TK5000 for a deep tubewell, but nothing has happened for 2-3 years. Actually people should pay TK4500, but they were charged TK5000. Some people alleged that the DPHE does not provide a receipt for the money that they take from people. If they do provide a receipt, it is produces on a piece of plain paper rather than on an official letterhead (Figure 7.14).

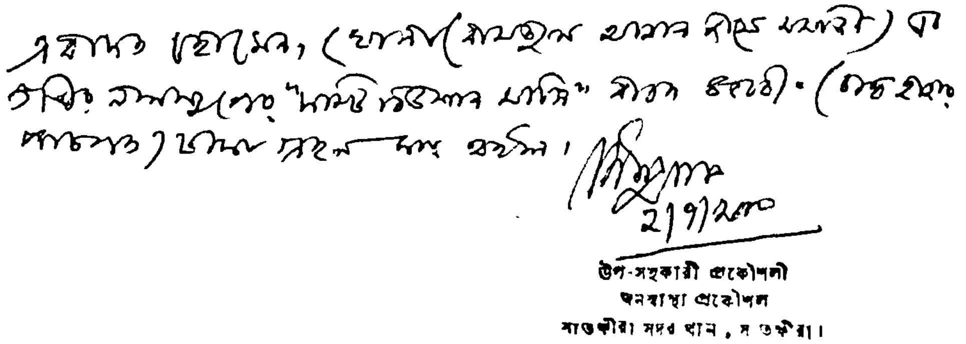
উপ-সহকারী প্রকৌশলী
জনস্বাস্থ্য প্রকৌশল
সাতক্ষীরা সদর থানা, সাতক্ষীরা।

Figure 7.14: A DPHE receipt for the contribution money for a deep tubewell on a plain paper signed by a sub-assistant engineer.
Source: Field survey, 2001.

Sometimes, receipts are provided without a signature or official stamp. The DPHE engineer of Satkhira Branch was said to be exploiting people under the banner of arsenic mitigation. The people I talked to were worried that if this engineer transfers elsewhere, or if he retires, they will get neither the deep tubewell nor their money back. One focus-group participant in this regard gave interesting information:

> ". . . . The DPHE engineer told me that if I pay the said amount now, I could get a deep tubewell within a month and if I pay later, it could take two to three more years to get a deep tubewell. As per his suggestion, I collected TK5000 from the local people for a deep tubewell. I paid the money directly to the DPHE engineer and requested a receipt. When I requested for a receipt, he then asked me, "why do you need a receipt? You don't need it when you have given money to me." When I told him that I have collected the money from local people and when they ask me whether I have paid the money, then how can I reply to them? The engineer then wrote down a note on a plain paper that I received TK4500 from Mr Ibadat Hussein rather than the official letterhead pad. There was no signature or official stamp, when I requested a stamp, he told me that "no, you don't need any stamp." However, at a certain point, he signed with an official stamp. A year has passed and I haven't got the deep tubewell yet." (Focus-group discussion, 2001).

Just after the flood of 2000, the DPHE engineers put bleaching powder into tubewells in the study area and people could not drink the water for a few days. However, they did not repair the recent flood damaged tubewells originally provided by them unless they were paid by the tubewell holder. Some tubewells in the study area have been found to be damaged. A DPHE-provided tubewell (Id: 139) was not working during the reconnaissance survey (Late December, 2000), but later when I collected a water sample from that tubewell, it was fully working and was a safe tubewell. The tubewell holder had repaired it himself a few weeks before, but it got damage again when I went a second time (Mid-January, 2001). In a question concerning the repair of the tubewell, he replied that, ". . . it is troublesome matter to make any contact to the DPHE engineers for repairing this tubewell. They will come and will not repair it until I provide them with money. The best way is to repair the tubewell on your own and not to tell the DPHE the situation." Some people pointed out that the DPHE men sometimes visit Ghona and they remove tubewell pipes and tubewell heads and keep tubewells inactive until they get money from the local people under the banner of repair costs (Figure 7.15).

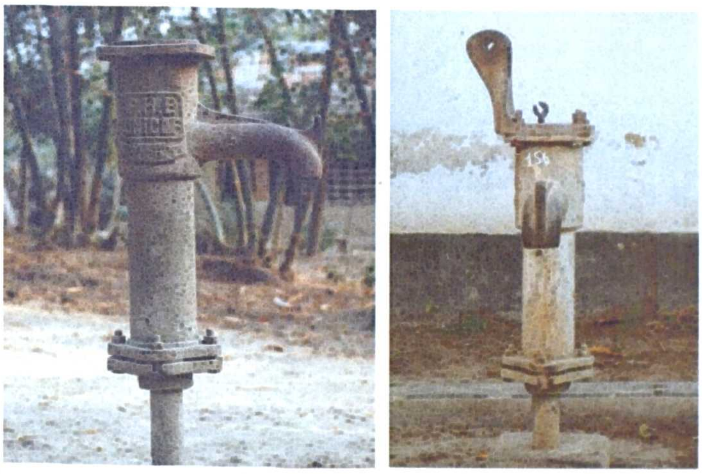

Figure 7.15: DPHE men took away tubewells or tubewell handles to earn money under the banner of repairing cost.
Source: Field survey, 2001.

When I started to collect water samples from tubewells in the study area, people thought that we were from the DPHE and that we were going to remove all of the tubewells from the study area. Some people were worried about their tubewells. Just after the flood of 2000, DPHE engineers visited Ghona and removed some tubewells provided by them after notifying people that the water was not pathogen-free. The same situation happened in Jhenidah district. The DPHE removed all of their tubewells with an assurance that they would be repaired, but they had still not been reinstalled six months later (The Daily Star: 30/06/2001, Bangladesh).

The elected administrators (Chairman and members) in the study area are unhappy about DPHE activities. They allege that the DPHE collects money from poor people for arsenic-free deep tubewell, but they fail to provide it. One elected administrator in this regard told me that, ". . . The DPHE takes TK5000 for each deep tubewell, but there is no fixed date to provide the deep tubewell. The DPHE is drawing out the implementation of their policy without any good reason." Since arsenicosis is a terminal disease, people thought that the DPHE should give priority to this issue, and that they have to provide the benefits of deep tubewell water to the rural people. If they charged a contribution of TK1000 rather than TK5000 from people, then more people would benefit from the installation of deep tubewells for arsenic-free water.

The DPHE analyses water samples at a nominal cost, but participants reported that they are not cordial and sincere in this. Some people pointed out their negligence in analysing water samples. A focus-group participant told a story about his experience of wanting the analysis of water samples by the DPHE: ". . . A few months ago, some of us went to Satkhira DPHE office with iron-rich red coloured water samples from our own tubewells for analysis. One officer of the DPHE took the samples and a few minutes later told us that all the water samples are safe and that there is no problem."

In some areas, almost all of the tubewells have already been sealed and put under red alert by the DPHE and professionals thought that analysing more tubewells would show them to be above danger level. The DPHE has taken to examine all the tubewells and this organisation has undertaken a comprehensive scheme to install deep tubewells in different areas (The Daily Star: 16/09/2001, Bangladesh). In a report, it has been found that two deep tubewells were sunk in Harishava of Faridpur by the DPHE for arsenic-free water, but they contain high levels of arsenic concentration (Anwar, 2001b). In addition, another deep tubewell installed by the DPHE for arsenic-free water was found to be contaminated with arsenic 40 times higher than the WHO standard (Anwar, 2001b). One wonders whether they took the trouble to analyse the deep aquifer before installing deep tubewells for arsenic-free water.

Some respondents claim that the DPHE misinforms people about the real situation of the water quality of tubewells. They make claims about the excellent water quality of the tubewells that they have installed, but some people have come to know that a few deep tubewells contain a certain level of arsenic and they are therefore not interested to provide a contribution for getting a deep tubewell.

7.5.3 Activities of health and family planning department

The government is continuing to work on arsenic mitigation. The health and family planning department under the Ministry of Health and Family Planning Welfare are involved. Through their satellite camp programme, they campaign on arsenic poisoning and safe drinking water. The main limitation of this satellite programme is that only those who participate in that programme can learn and benefit. A family-planning officer told me that:

> ". . . . It is our duty to let the people know about arsenic problems through our satellite programme. We are planning to provide training to *Moulvies* (religious teachers) of the *Madrashas*, *imams* of mosques, and some other people to take the awareness campaign programme to the houses of the people." (In-depth interview, 2001).

When people first came to know two years ago that arsenic is concentrated in tubewell water in Ghona, the family-planning department arranged a course on arsenic to train-up some local health workers, local village doctors, teachers and so on for an awareness campaign. The concept was that the trained people would pass the arsenic message to others and those to others again.

Health workers of the health and family planning department are contributing. They are working on arsenic issues apart from rural sanitation and family planning. They have grassroots contacts with the people, but some respondents alleged that health workers do not do anything directly on arsenic.

> ". . . . They do not do their work properly. If people are attacked with diarrhoea and go to them for medicine, then they advise people to buy a packet of saline and to drink after dilution with water. Their responsibility should be to provide patients with cost-free saline." (Focus-group discussion, 2001).

However, most people do appreciate health workers for their role in many aspects of health. They do go to the doorstep of poor people to provide them with health services, and they could therefore contribute to the combating of arsenic problems. They could visit every housewife in every household in rural areas and discuss the impact of arsenic and how to combat it. On the positive role of health workers, one focus-group participant cited an example of diarrhoea.

> ". . . . A few years ago when there was a serious diarrhoea problem in Ghona, the health workers went to every household and they taught them how to make a saline solution with salt and sugar to treat diarrhoea. This saline saved many lives. The poor people who could not afford to buy saline, made it by mixing salt and sugar." (Focus-group discussion, 2001).

They could sharpen public awareness by advising people to drink filtered water, or arsenic-free deep tubewell water, or to boil surface water to drink.

The Ghona Health Complex is contributing to providing health services to local poor people. If the government adopts a policy to give special medication through this institution, arsenic-affected people could benefit, but some participants criticised the Ghona Health Complex for its activities. It was said that they do not take care of the poor patients and, sometimes, do not provide proper medicines to poor people. Also the opening hours are felt to be inadequate.

Doctors could play a contributory role. When people get sick, they first go to a doctor. It has been observed from the field survey that village doctors in the study area are not aware about arsenicosis except for a few and they provide arsenic-affected patients with the wrong prescription. They are confused by arsenicosis with sores on palms and soles. If they had proper training on arsenic issues, they could be more effective. Many people have come to know recently that no curative medicines have yet been invented for arsenicosis and that doctors' prescribing practices are therefore flawed.

7.5.4 Local elected administrators

Rural people always appreciate their own representatives since they have direct contact with them. People always trust their own representative more than anybody or any organisation. There is a direct contact between lay people and their representatives and they can always focus their problems to these elected administrators.

In the survey people thought that the elected administrators could raise arsenic problems in their monthly meeting with the UNO at the Satkhira *Upazila* Headquarters. They could also discuss problems with the DPHE concerning monetary contributions for deep tubewells. They can focus people's problems concerning arsenic issues to the higher authority through the UNO. But, in a question concerning the role of Chairman and Members in the arsenic mitigation issue, some respondents thought that the elected administrators could not do more in solving arsenic problems because they do not have any financial support. One elected member added here, ". . . We do not have any direct contribution in arsenic mitigation. If the government take any decision in this regard, we can send it to the doorsteps of our people."

In a focus-group discussion with the Union Councils, they criticised the role of the government for not having done enough to combat arsenic poisoning, and said that they have not received any concrete suggestions from the government about alternative sources of safe drinking water. Participants pointed out that the government and donor agencies have the tendency to implement their policies through the NGOs rather than involving the people's representatives. Union Councils could be the focal point in arsenic mitigation activities in a bottom-up approach, not top-down measures.

Some people thought that the elected administrators of the study area do not have enough power and experience to tackle arsenic problems. They could only help by arranging deep tubewells from the DPHE for people as the previous Chairman did. The previous Chairman of Ghona *Union* arranged twelve deep tubewells for this *Union* in 1998. The present Chairman has been collecting TK5000 for each deep tubewell for the last two years.

Some people in Ghona gave their contribution money to their Chairman and members for deep tubewells, but they do not know whether they had arranged anything for them or not, or whether they provided their money to the DPHE or not. A member of Ward - 1 paid TK15,000 for three deep tubewells in 2000 to the DPHE, but has not heard any feedback. One elected member was said to have misappropriated TK5000 for a deep tubewell two years ago and that he did not pay the money to the DPHE. One focus-group participant reported his experience in this case:

> ". . . . I provided my Chairman TK5000 for a deep tubewell, but I do not know whether my Chairman paid the money to the DPHE or not. When I made contact to the Chairman and asked him about the issue, he replied that everybody who already paid money would get a deep tubewell shortly after allocation. He also told me that the installation process of deep tubewell is different from that of normal tubewell and it is only possible to install a deep tubewell by a specialised engineer. My Chairman also told me that the DPHE installs deep tubewells *Union* to *Union* on the basis of first come first served. They will not install any deep tubewell in any *Union* until finishing one *Union* from where they started to install deep tubewells. This is the main cause of this delay." (Focus-group discussion, 2001).

Some people thought that **local leaders** (*mattobbar*) could contribute to arsenic awareness campaigns. They could advise people about arsenic poisoning and its mitigation options in their own vicinity.

7.5.5 Government activities

The government has taken various measures to provide arsenic-free drinking water to the people through alternative sources, but these are not good enough as either an urgent or a permanent solution. The LGRD and Cooperatives Minister at the Jatiya Sangsad (National Assembly) on 28/11/2001 pointed out the activities that the government has undertaken. Different projects have been initiated for detecting arsenic contamination and providing adequate treatment for affected people. He focused mainly on rain-water harvesting as a means of obtaining arsenic-free drinking water (The Daily Star, 29/11/01, Bangladesh).

The government plans to launch an "Arsenic Public Health Project" in assistance with the WB and the Government of the Netherlands, which emphasises health aspect of arsenic contamination (www.worldbank.org/pics/pid/bd76693.txt). The government would focus on the health aspect of the arsenic crisis, as no drug treatment is available (The Daily Star, 15/11/01, Bangladesh).

The government has the tendency to blame its predecessors for not doing anything substantive in any regard and vice-versa. Mitigation measures undertaken so far by all the governments are inadequate, as the problem is new and unprecedented. In some severe cases, the government has only undertaken a comprehensive programme for sinking tubewells in the rural areas affected (The Bangladesh Observer, 07/07/01).

Since arsenic is a national problem, the government is ultimately responsible. But, after the first detection of arsenic concentrations in groundwater in 1993, the government did not take the issue seriously enough. Also, it is the responsibility of government to monitor NGO activities. One focus-group participant in this regard said that:

> ". . . . It is not the fault of NGOs, it is the fault of the government since the government is not monitoring them. The government has given NGOs licence to conduct works for socio-economic development. If the government is straight, then it is not difficult to mitigate arsenic problems in Bangladesh. However, the government is not straight in arsenic issues and they see nothing even after seeing everything. The government is making politics on the arsenic issue." (Focus-group discussion, 2001).

Some people thought that the government could take quick action through different international donor agencies, and deal with arsenic problems within years. As an example, every year the government gets financial support from many donor agencies and rich countries for the development of different sectors and in a similar way, if government were to get financial support from them for arsenic poisoning, they could solve the problem by installing deep tubewells. Most focus-group participants responded positively to this suggestion.

Respondents thought that where people are affected with water-borne diseases like cholera, diarrhoea and abdominal problems as well as recent arsenic poisoning and cancer, the government should take quick action in this regard. One respondent told, ". . . Many organisations or many professionals can make people aware of arsenic, but the mitigation policy should come from the government."

7.6 NATURAL OPTIONS for ARSENIC MITIGATION

I have discussed different suitable preventive measures and low cost technologies for arsenic mitigation. In this section, there will be consideration of the possibility of adopting the natural mitigation options that could be environmentally supportive. This is not about minimising arsenic concentrations in groundwater but rather removing arsenic altogether from drinking water.

7.6.1 Back to surface water irrigation

The study area is characterised by a multiple cropping intensity. Despite rain in winter, irrigation is necessary to grow the *Rabi* (winter) crops in the study area. Irrigation by mechanised means (e.g. mainly the shallow tubewell and deep tubewell) began in the early 1960s (Rashid, 1991) and at that time only surface water sources (rivers, canals, *beels* etc) were drawn upon using Low Lift Pump (LLP) (Hossain, 1991). Since a sufficient quantity of surface water was not available during the dry months, mechanised tubewells of various bores were introduced to tap groundwater heavily for irrigation. It has been found from the field survey that during the dry months, most hand-pump tubewells (82.40%) do not have any water available for regular use due to the heavy withdrawal of groundwater by mechanised shallow tubewells and deep tubewells for irrigation.

Government aims and policies for agricultural development are to increase food production in order to reduce food imports (Alauddin and Tisdell, 1991). The government slogan was to build '*Sonar Bangla*' (Golden Bangladesh) during 1972-1975 and '*shobuz biplab*' (green revolution) between 1975 and 1982 (Hassan, 1997). The government undertook the strategy of using new technologies with the increased distribution of chemical fertilisers and mechanised shallow tubewells and deep tubewells for '*Sobar Zonna Dal Bhat*' (lentils and rice for all), a national slogan established in 1996 (Hassan, 1997).

Arsenic from contaminated water of shallow aquifers through irrigation will penetrate through the roots to crops, vegetables and fruits and finally come to humans through the food chain to cause arsenicosis. If arsenic contaminates the food chain, people will ingest arsenic from both the contaminated drinking water and contaminated foods.

Since the study area is in the Ganges-deltaic zone, surface water sources in the study area exit in the form of <u>closed</u> and <u>open</u> water bodies[4]. Canals, ponds, ditches etc are available in the study area and it is possible to consider the use

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[4] The **closed** water bodies are mainly constructed artificially bounded by embankments. These are mainly private property and are inherited according to the law (Ghosh, 2002). People only have access these water bodies for bathing or daily use rather than irrigation and fishing. *Pagar* and *doba*, *pukur* (pond) and *dighi* (tank) come under this category. The villagers perceive *doba* and *pagar* differently and both the terms are used in English literature as 'ditch'. A *doba* is normally constructed by removing soil from one place to another for raising land for homesteads to make it flood-free; while a *pagar* emerges when soil is dug out to construct a road or to raise land for making it suitable for some crops but not to construct a homestead. A *doba* is irregularly shaped and may hold water between five to eight months depending on its size and depth (Ghosh, 2002). When this *doba* is increased in shape and depth, it may be termed a pond. It is difficult to distinguish between *pagar* and *doba* by size, but normally a *pagar* is smaller than a *doba* and retains water for fewer months. Canals can be considered as **open** water bodies. Two canals and many closed water bodies are found in the study area.

of water from these sources for irrigation (Figure 7.16). Water is also available in canals flowing in the study area except for some interruptions. By dragging the canals and linking them with the main river adjacent to the study area, water could be available all year round.

The study area covers about 78.27% (13.51 km^2) of agricultural land and almost all of the agricultural land is considered to be irrigation command area in the dry months and the mechanised shallow tubewells and deep tubewells cover the agricultural land under irrigation. Based on the field survey and a GIS buffer operation, it can demonstrate that it is possible to continue irrigation from the surface water sources of the study area (Figure 7.16).

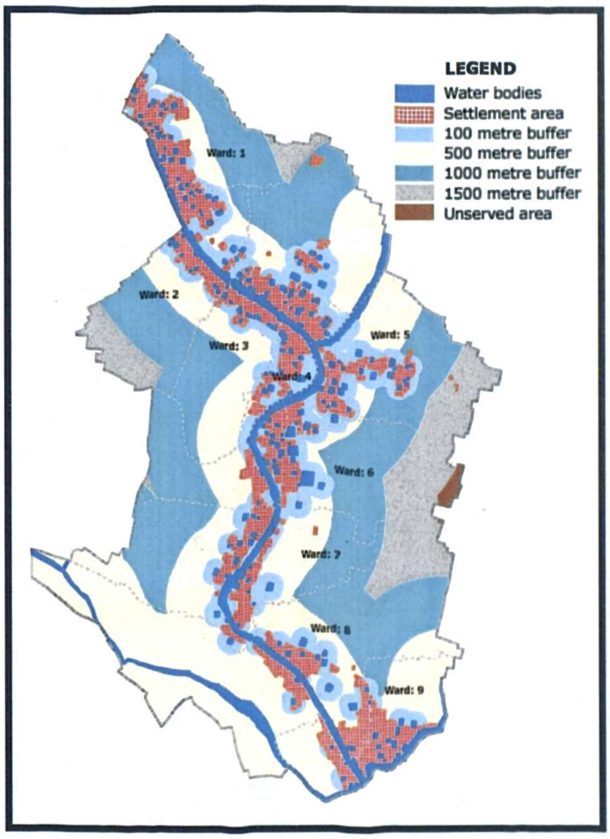

Figure 7.16: Buffers of surface water bodies.

It is noted here that during 1977-81, the former Bangladesh President for his '*shobuz biplab*' (green revolution) undertook a principal strategy for agricultural development. Apart from the use of mechanised means of irrigation, he established the "canal excavation policy" (*khal kata kormochuchi*). This policy could be applied for irrigation in recent times to avert groundwater arsenic poisoning in soils and food chain. It is also noted that the proper excavation of canals could lead to proper use of surface water for irrigation.

In considering the oxidation hypothesis, we may speculate whether is it possible to make a policy for using alternative water sources for irrigation rather than groundwater. Heavy withdrawal of groundwater is the cause of arsenic concentrations. Canals and many closed water bodies are available in the study area and it is possible to provide water for the *Rabi* crop from the surface water sources rather than groundwater. Therefore, a policy for stopping the use of groundwater for irrigation can avert arsenic poisoning.

It has been found from the literature that arsenic can enter the food chain when groundwater is used for irrigation (Dabeka *et al*, 1993; Gunderson, 1995; Chowdhury *et al*, 2002; and Tsuda *et al*, 1995). Moreover, inorganic arsenic in dietary staples (*i.e.* yams and rice) may have substantially contributed to exposure and adverse health effects observed in an endemic Taiwanese population historically exposed to arsenic in drinking water (Schoof *et al*, 1998). If the government makes a policy to remove arsenic from groundwater for drinking and cooking purposes, I think that this will be an inappropriate decision. What will the government do if arsenic attacks humans through food chain rather than drinking water? The wise solution would be to stop the use of groundwater altogether.

7.6.2 Switch over the drinking water culture

From the field survey we can see that the study area is full of surface water sources (Figure 7.14). Decades ago, people of the study area used to drink and cook with pond water. Some used to purify pond water with camphor, some people used to boil it before drinking and others used to filter it (details in chapter – V). There was a tradition that a particular pond was used for drinking and cooking purposes, and there should be no bathing, washing of clothes, or other activities that might contaminate that pond water. People used that water only for their drinking and cooking purposes. For any emergency policy, where there are no alternatives, people should switch back from their present tubewell water culture to their previous pond water culture. If there are no alternatives, the government could prepare some ponds in arsenic contaminated areas as reservoirs and these could be taken care of specifically as reservoirs.

Generally, surface water in most places has no risk of arsenic contamination other than microbiological contamination. In Bangladesh, people are using groundwater for every one of their purposes and they are ignoring potential sources of natural water. Before the advent of tubewells, people used to use surface water and live with micro-organisms. However, as time passed, people have developed tubewell culture in order to reduce incidences of water-borne diseases. People may find it difficult to shift back to the past habit that has been altered over three decades, but it is still worth noting that a shift in habit would cost nothing. People have to boil water before using it, which is still a traditional practice in many parts of the country where no tubewell is available, as in the Barind region of North Bengal, Bangladesh (The Daily Star: 06/07/01, Bangladesh). However, some researchers point out the importance of chemical methods, and their opinion is that before using the surface water, it is necessary to remove certain toxic chemicals.

All of the government preventive measures in arsenic poisoning could be accomplished, if water is available in ponds, tanks, reservoirs, or dug-wells. It has been found from the field survey that during the dry months most of the tubewells remain dry, there is no water availability in most of the small water bodies (e.g. *pagar*, *doba*, and ponds) and dug-wells also remain dry. Villagers told me that before the Liberation War (1971), when there were no mechanised deep tubewells and shallow tubewells for irrigation, water was available in all ponds, dug-wells and hand-pump tubewells. Therefore, water could be available from surface sources during the dry months if the pumping of groundwater for irrigation is stopped.

7.7 ARSENIC FACTS: POLICIES and POLITICS

There is a tremendous lack of coordination among the agencies working to address the groundwater arsenic poisoning. Very few organisations have shared data or information with others or with other agencies working on the same problem. Despite repeated calls for coordinated efforts to address the issue, many are not cooperating (The Daily Star: 21/08/01, Bangladesh).

There have been many projects on arsenic in recent years, but few have been effective to point out the real problems and solutions of arsenic poisoning. It has been found from various sources that the outcome of any arsenic mitigation project of the WB, the UNICEF, the WHO, the DANIDA programmes has not reached the poor people yet. They are providing financial and technical supports for identifying arsenic problems and its mitigation options.

The WB provided financial support (US$44m) for the BAMWSP project, but this project was not completely successful. The WB is going to lunch soon another arsenic related project (Arsenic Public Health Project-APHP) worth US$45m to find the health and environmental problems associated with arsenic even though there was a very little success with the BAMWSP project. There is some repetition in the objectives of the BAMWSP and APHP projects. Very few people have so far benefited from these expensive arsenic mitigation activities.

7.7.1 Activities of the BAMWSP

Recently the BAMWSP has been serving as an umbrella for an ambitious national water testing and health survey. Further studies and action programmes are being implemented or planned by a number of government and non-government agencies as well as many donor agencies. The BAMWSP activities do not cover the full-phase arsenic poisoning and the real solution of the problems. For the BAMWSP project, US$44m has been approved for arsenic mitigation based on an outdated 1940s standard with inaccurate and semi-quantitative arsenic analysis techniques.

The BAMWSP found 52.15 per cent of the total tubewells free from arsenic contamination during a survey in 31 *upazilas*. A total of 425,460 tubewells were tested during the survey and 221,887 of them were found to be arsenic-free (http://www.bamwsp.org). However, 5346 people were identified as arsenic patients in these *upazilas* during the survey, which mainly focused on testing of arsenic levels in tubewell water, identification of arsenic patients and creation of awareness against arsenic at the grassroots level (http://www.bamwsp.org).

Several domestic water treatment methods by the BAMWSP are at various stages of development, testing or distribution. The suitability of these technologies to the household needs, recurrent cost for operation and maintenance of these treatment units will be an added burden to the poor (even to the rich) in addition to the investment/installation cost, in rural areas (Khondaker, 2001). Questions about which long-term safe water strategy is the most suitable for Bangladesh are vigorously debated. A return to the use of (treated) surface water is under consideration (Hanchett *et al*, 2000). A review article also criticised the activities of the BAMWSP in arsenic mitigation planning (Anwar, 2001a). Donors do not clearly know what is being done at the field level. When I was with the BAMWSP (from April 1999 to September 1999), I saw that many activities could not be implemented by the BAMWSP.

Anwar (2001b) pointed out that two new tubewells were drilled under the BAMWSP arsenic mitigation programme in Faridpur and both of them were found to be highly contaminated with arsenic and one tubewell contained 1.76 mg/l of arsenic and another tubewell was measured as to be 40 times higher than the WHO standard. Unfortunately, people were drinking this contaminated water as it was certified to be safe by the BAMWSP.

7.7.2 Activities of the UNICEF

The assistance of the UNICEF to the DPHE in promoting groundwater is an important aspect for the drinking water. The UNICEF has become an important contributor to reducing high mortality rates from cholera, dysentery, diarrhoea and other water-borne diseases by providing people pathogen-free tubewell water years ago. These tubewells now contaminated with arsenic and people who drink this water are suffering from arsenic-related diseases.

In a workshop at the National Press Club, Dhaka organised by the Forum of Environmental Journalists of Bangladesh (FEJB) with the cooperation of Ministry of Health and Family Welfare and the UNDP, some speakers mentioned that people affected with arsenicosis are preparing to sue the UNICEF and the DPHE for keeping them in dark about the dangers of arsenic-contaminated tubewell water that the authorities promoted as safe drinking water (The Daily Star, 18/07/1999, Bangladesh). In addition, a newspaper reports that "a newly formed organisation is threatening to sue the UNICEF for compensation on behalf of the millions of unsuspecting victims of arsenic poisoning who are slowly dying in Bangladesh" (South China Morning Post, 20/07/1999).

The UNICEF did not monitor the quality of drinking water regularly in terms of its toxic chemical contents. Amidst their enthusiasm to drill tubewells in Bangladesh in the 1970s, the UNICEF forgot about the Taiwan experience (The Daily Star, 10/03/1999, Bangladesh). But the enquiry will focus on how it was possible for the deadly water to remain untested for two decades?

7.7.3 Activities of the BGS

The British Geological Survey (BGS) carried out studies on behalf of the Bangladesh Government in the mid-1980s and early-1990s. But, the British scientists "failed to detect dangerous levels of arsenic in the supply of drinking water implicated in the biggest mass poisoning in history" (Connor and Pearce, 2001). Two studies of groundwater quality in Bangladesh carried out by British hydrologists failed to monitor natural arsenic levels.

The BGS in its report in 1992 did not mention arsenic in groundwater in Bangladesh although the WHO recommends testing for arsenic for drinking water quality test. They knew of the groundwater arsenic problem in West Bengal (India) which was discovered in 1983 (The Daily Star: 27/07/01, Bangladesh). During 1991-92, a BGS team surveyed the quality of groundwater in thousands of tubewells in central and northeastern regions of Bangladesh and the BGS in its report said that the water was 'safe for drinking'. A few years later, it was detected that water in many parts of the regions studied had high levels of arsenic (The Daily Star: 27/07/01, Bangladesh). Moreover, the BGS did not work with Geological Survey of Bangladesh (GSB) on geological investigations (Anwar, 2001a).

More dangerous is their recommendation for deep tubewells, as they reported that, "available data shows that aquifers deeper than 150-200m are essentially arsenic-free over much of Bangladesh. Systematic sampling showed only 2 out of 280 wells deeper than 200 metres to be contaminated" (BGS, 1999). On the basis of this report, donor-aided arsenic mitigation projects installed several hundreds of deep tubewells. The UNICEF allocated two million dollars to the DPHE for the installation of some 5,500 deep tubewells (Lockwood, 1999: UN Resident Co-ordinator, in; The Daily Star, 07/09/2001, Bangladesh). Such drilling has now contaminated most of the deep aquifers of Faridpur, Kushtia and other northern districts (Anwar, 2001a). In view of this, we may ask who will take responsibility for the poisoning resulting from the contamination of the deep aquifers.

Many donor organisations have been involved in development activities in Bangladesh. They provide financial support in many sectors of development. In arsenic issues, they are also providing help. But, the arsenic mitigation programme financed by the WB is subject to inefficiency, bureaucracy, corruption, lack of capacity, lack of capabilities and lack of professionalism (Hoorens and Koenders, 1999). So far, no programme of aid has really reached the people who need it.

7.8 CONCLUDING REMARKS

I looked at the arsenic awareness campaign through its toxic nature and mitigation options during my field survey. An attempt was made to uncover people's perceptions about the different mitigation options proposed by different organisations. This chapter has mainly discussed people's voices about the suitable awareness raising policy for arsenic poisoning and some mitigation options and their applicability and suitability.

The chapter has explored the roles of different government organisations, NGOs, and different professionals in mitigating arsenic problems in the study area. Works of different organisations and professionals has also been reviewed. Many governmental organisations are campaigning and announcing repeatedly and frequently about arsenic awareness issues and about drinking fresh-water through media such as radio, television and national newspapers, but most of the people do not give these statements any credence. When I raised this issue during in-depth interviews and focus-group discussions, people said that they are unable to afford a television or even the batteries for a radio; and few can read newspapers. Apart from this, people thought that quick and effective awareness campaigning is possible if the government campaigns on arsenic issues like they do on AIDS, floods, population problems and so on.

Only a very few people knew about the true impact of arsenic poisoning before my fieldwork in the study area. Now most of the people of Ghona have come to know about arsenic and its impact on health and social aspects. Some people are changing their water-use habits and are drinking safe water from deep tubewells. Almost all focus-group participants told me that, ". . . People are more aware of arsenic poisoning now than three months ago. People have come to know if arsenic once attacks they will die without getting any proper treatment".

I have discovered from my study that there has developed a hidden business in mitigating arsenic problems. NGOs are continuing their business under the banner of socio-economic development within their micro-credit programmes;

the DPHE is conducting business in the name of providing people with arsenic-free deep tubewells; elected administrators are collecting money in advance for deep tubewells; and village doctors are providing arsenic-affected patients with useless but expensive prescriptions.

In the discussion of low-cost available arsenic removal technologies and its use, some poor people said that they could not use these technologies since they cannot afford them and it is not important for their daily life. Their opinions are mainly focussed on the continuation of the tubewell practice. Since arsenic poisoning still is a relatively new issue, people do not take it seriously. If people come to know that no curative treatment of arsenicosis has yet been invented, consciousness will spread quickly.

This chapter has addressed people's perceptions about arsenic awareness and suitable mitigation options, what they think and want to adopt as a solution they envisage. The next chapter (chapter VIII) will summarise the thesis using new concepts of arsenic research and make some recommendations in view of the arguments and data deployed in this thesis. In addition, it will point out the applicability of the methodological aspects adopted for this research.

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CHAPTER VIII

SUMMARY and CONCLUSION: DEVELOPING NEW CONCEPTS and RECOMMENDATIONS

CHAPTER – VIII

SUMMARY and CONCLUSION: DEVELOPING NEW CONCEPTS and RECOMMENDATIONS

The function and utilities of spatial, quantitative and qualitative analytical procedures in arsenic poisoning provide analytical information about human health and social issues for decision-making and planning. An attempt has been made in this thesis to promote a concept of the impact of arsenic poisoning on human health and social aspects in the study area using data and method triangulation in terms of spatial, quantitative and qualitative techniques. Spatial and quantitative studies have identified the scale of arsenic concentrations in terms of spatial arsenic magnitudes, arsenic magnitudes with depth and time; and spatial risk characterisation. The qualitative study examined the people's perceptions about arsenic, arsenicosis, risk, health and social difficulties they are experiencing, and survival strategies adopted by them. Suitable arsenic mitigation options following the environmental and technological considerations were also investigated.

8.1 EMPIRICAL-ANALYTICAL FINDINGS

The spatial and quantitative data have provided empirical-analytical findings in the form of geographical distribution of arsenic concentrations with the issues of spatial risk characterisation producing 'problem regions' or 'risk zones' for composite arsenic hazard information. In addition, this study has examined the applicability and functionality of GIS analytical techniques in the light of the pattern of 'spatial risk zones' of arsenic concentrations. The GIS techniques in this study have been demonstrated as an excellent tool to handle a wide range of arsenic databases in a meaningful form. From the overall discussion, the following key findings can be summarised.

8.1.1 Scale of groundwater arsenic concentrations

Spatial arsenic concentrations: A field survey was undertaken to analyse the scale of groundwater arsenic concentrations in the study area. All of the collected samples $(n = 375)$ were analysed by the FI-HG-AAS techniques and the spatial patterns of arsenic magnitudes were measured by IDW, RBF and Ordinary Kriging methods. The spatial pattern of arsenic concentrations in the study area is highly uneven ranging between <0.003 mg/l and 0.600 mg/l (Table 4.3), and almost half of the tubewells are located within 25 metres of each other (Figure 4.9). The geostatistical prediction maps also reveal safe zones that are mainly concentrated in the north, central and south part of the study area in a scattered manner; while the contaminated zones are concentrated in the west, northeast and east (Figures 4.6 and 4.7).

Only 1.07% of tubewells meet the WHO standard level (<0.01 mg/l) and about 3.50% tubewells qualify within the DoE permissible limit (<0.05 mg/l). In the contaminated band, about 95.50% of the tubewells are found to be contaminated with arsenic ranging from 0.057 mg/l to 0.6 mg/l (Tables 4.3). It is noteworthy that the $\bar{X}$ arsenic concentration in this contamination category is 5 times higher than the DoE standard limit and 25 times higher than the WHO permissible limit.

Arsenic with depth: There are highly uneven arsenic concentrations with aquifer depth in the study area. There is an increasing pattern of arsenic concentrations with depth down to at least 75 metres, with some regional variations (Figure 4.10). A very little contamination was found in tubewells tapping the deepest aquifer (>150 metre depth) with concentrations of ≤0.05

mg/l (Table 4.5) and, for the shallow aquifers (≤150 metre depth), almost 98% of the tubewells are contaminated, while only 2% are safe following the DoE permissible limit. There are no safe tubewells if the WHO guideline value is used for the deep aquifer.

From the GLMs, there is a low negative correlation ($r = -0.0999765$) between arsenic concentrations and aquifer depth. The bell-shaped inverse quadratic trend line and the lowess trend line have shown an increasing trend of arsenic concentrations up to a depth of 75 metres and a decreasing trend beyond that (Figure 4.10). The nugget variance of spherical semivariogram model represents a considerable locally erratic component of the variation of arsenic with depth (Figure 4.11).

The correlation coefficient values and the scatter diagrams with polynomial trend lines for nine administrative wards suggest a paradoxical regional variation of arsenic concentrations with aquifer depths (Figure 4.13). The study shows varied pictures of the arsenic-depth relationship, while Nickson *et al*, (1998) show a decreasing trend of arsenic concentration with increasing aquifer depth. The maximum arsenic contaminated wells (>0.05 mg/l) seem to occur especially within the depth ranging between 20 and 100 metres in the study area. The nugget effects for different aquifer depths show the variability of arsenic magnitudes in different shallow aquifers (Table 4.6 and Figure 4.14).

Arsenic with time: The GLMs also show a very low positive correlation ($r = 0.208$) between arsenic concentrations and the installation year of tubewells. The coefficient values show that the older tubewells have more arsenic than those installed recently. Since people continue to withdraw groundwater mainly for irrigation purposes, this could be the cause of arsenic entering into the groundwater. The inverse quadratic trend line and the lowess trend line shows a slight of arsenic with time (Figure 4.15) indicating that the more groundwater is tapped the more arsenic will concentrate.

8.1.2 Risk characterisation and spatial risk zoning

Risk characterisation: Risk characterisation of drinking water arsenic ingestion has been assessed by calculating the exposure and toxicity. The estimation of environmental health risk with uncertainties in this thesis has been described within a range of probabilities and has been seen as a 'best guess', rather than an irrefutable statement of fact. The 'risk ratio' shows that people who are ingesting arsenic between 0.01 and 0.05 mg/l daily are twice as likely to get arsenicosis symptoms as people who get arsenic at the safe level (<0.01 mg/l), and those who are ingesting arsenic at >0.3 mg/l are 11 times as likely to get arsenicosis symptoms as people exposed to <0.01 mg/l (Table 4.10). This thesis has shown that there is a chance of about 95 people in the area dying with arsenicosis if they consume arsenic at 0.05 mg/l for a lifetime; while 157 people will die with arsenicosis if they continuously intake arsenic for their lifetime at 0.1 mg/l. The assessed risk for 0.1 mg/l of arsenic would be 26/1000 people, rising to 130/1000 people if arsenic concentration in drinking water is 0.5 mg/l.

Spatial risk zones: GIS analytical methods have been applied in identifying 'spatial risk zones'. Using GIS overlay techniques a cartographic model was developed in which the arsenic exposure data layer was created by combining the map data of spatial arsenic magnitudes and buffer data of tubewell users. The exposure data layer was then overlaid with the map data of the settlement area to yield a characterisation of four different risk zones (Figure 4.21). The safe zones are located in the central and southern part of the study area covering only 3.17% of the settlement area with about 16% of the population. The low risk zones are located in the northern, central and southern parts of the study area with 4.18% of the settlement area having some 12.50% of population. The medium risk zones are distributed from north to south along the middle of the study area covering about 39.64% of the total settlement area having about 28.75% of the population. The high risk zones are mainly located in the west and northeast part of the study area covering about 53% of the total settlement area and about 42.75% of the population live in this category.

8.2 QUALITATIVE FINDINGS

The qualitative method in this research brings forth in-depth realities about the impact of arsenic toxicity on human health, and social issues and people's coping strategies concerning arsenic poisoning. Qualitative modes of analysis have mainly been concerned with textual analysis to build new understandings about the impact of arsenic toxicity on health and social issues.

8.2.1 Terminological issues: people's understandings

This thesis has explored people's perceptions about the terminological issues of arsenic, risk, social risk, health hazards, and social hazards, and what has changed in the last few years regarding the groundwater arsenic contamination. The ideas of unaffected people about 'arsenic' and 'arsenicosis' were mainly confined to poison, germs and diseases like eczema, leprosy, gangrene and cancer, while perceptions of the arsenicosis patients are confined to black spots, blisters, itching, and hard and rough palms and soles that they are experiencing.

People's perceptions about 'risk' are mainly confined to the 'possibility of adverse health effects', 'possibility of death' and 'cause of danger'. 'Social risk' is defined by lay people as the 'chance of social difficulties' or 'possibility of social hazard' or 'possibility of social harm' or 'likelihood of social humiliation'. In defining 'health hazards' people think of 'anything dangerous that happened to human health'. Some people think of 'social hazards' as the cause of 'social negligence' or 'social degradation'. They considered a social hazard to be 'social inequality' and 'social injustice'.

8.2.2 Arsenic exposure: health and social hazard

Recognition of health effects: Since arsenic poisoning is new, patients ignore the symptoms of arsenicosis during the early stages of their illness and they deny the severity of symptoms due to their unfamiliarity. The poor people are the sufferer and they ignore them because poverty has captivated them. Arsenicosis patients describe their disease generally as a black spot, which is locally known as 'zengo'. At the primary stage of their illness, swollen spots develop on palms and soles and there is itching. Then these swellings turn into black spots which develop slowly. Later the skin becomes dark in a spotted form due to the deposition of a black pigment. These spotted black pigments on the palms and soles then become thickened and hard. A considerable number of unaffected people assume that long-term ingestion of arsenic could lead to a cancer risk.

Recognition of social effects: This thesis reveals many inherent social problems of the arsenic-affected people. The arsenicosis patients in the study area pointed out societal problems caused by arsenicosis – they are being isolated in their society. Within their community, patients are barred from social activities and often face rejection, even by their immediate family members.

The difficulty of getting daily work or interruptions of daily labour are major consequences of arsenic poisoning. When employers found that people suffered from arsenicosis, nobody was willing to provide them with any work. School children are also affected. Friends of affected children avoid sitting close to them and keep their distance, and they even do not like to share books, pencils and so on, and they do not play with affected children in school.

Children are not close to their parents and the parents feel hesitant about being close to their children. Moreover, husbands keep a safe distance from their wives. In fear of such social problems, people feel hesitant about expressing themselves about their illness. It is noted that arsenicosis patients are experiencing social isolation, social ignorance, and social injustice due to their illness.

Survival strategies: This thesis has investigated the ideas of arsenic-affected people about how they manage their health and social situation during their illness. The most important coping strategy considers different medical treatments that patients are adopting. Seriously affected patients usually go to a doctor. Three types of medical treatments are carried on in the study area: (a) allopathic treatment – most patients take this treatment since they think that this is the most rapid and reliable treatment in ensuring recovery; (b) homeopathic treatment – mainly poor patients assume that this treatment can lead to a cure, although the medicines work slowly; and (c) ayurvedic treatment – some use this treatment in which medicines are made directly with various plants and there are said to be no side effects and a purification of the blood. Apart from this, many poor patients go to quack doctors since they have lost their trust in other mainstream doctors. In addition, some rural poor people believe in traditional treatment systems and wearing amulets on the arms or waist, rubbing charmed oil and taking charmed water on the wound.

Under the adapting strategies, some patients have decided on the continuation of medicines until they recover. Most of the people are keen on the installation of deep tubewells to access arsenic-free water since they have come to know that arsenic-free water is the only preventive measure for arsenic toxicity. Some patients have taken the initiative in getting arsenic-free water by filtering pond water. Boiling the drinking water is a traditional preventative against cholera and diarrhoea, but currently, people are not willingly interested to boil pond water. Their main adapting strategy is to collect arsenic-free water from the nearest deep tubewell. The use of camphor in water and harvesting the rainwater are also their survival strategies.

In avoiding social embarrassment, some arsenicosis patients keep a safe distance from unaffected people. Some patients are keeping distance from other of their family members. School children affected with arsenicosis refuse to go to school, some children do not reveal their arsenic problems - they cover them up in school so that their friends will not find them out as arsenicosis patients. Apart from this, under the behavioural adjustment measures, patients try to regulate their activities with regard to their disease and social problems – they do not like to collect arsenic-free water from deep tubewells due to social constraints.

8.2.3 Arsenic awareness and mitigation options

Suitable awareness campaigning: The thesis shows people's voices about the awareness raising policy for arsenic poisoning with mitigation options and their applicability. The government is continuing to conduct its awareness campaign over the radio, television and newspapers, but the campaigning procedures are not strong enough to make people aware. Since only a few people in the study area have got television and most are illiterate, the awareness campaign through these media is not effective. Therefore, cinema film and theatre staging could be utilised for a quick awareness campaign for the poor rural people in the study area. In addition, announcements about arsenic issues with a loudspeaker and several public meetings at Ghona would assist a quick campaign.

Labelling tubewell spouts with a green or red colour based on arsenic-free or arsenic-contamination is important in the awareness campaign. People are advised not to use red-labelled tubewells for drinking and cooking other than domestic purposes. The arrangement of short training courses for different working groups would be productive. After receiving training on arsenic issues, people could subsequently contribute to the arsenic awareness campaign for preventive measures. Apart from this, school and college teachers, *imams* of mosques, local leaders and social activists could also contribute if they get short-training from government.

Suitable mitigation options: The thesis focuses on some preventive measures and technological options for arsenic-free safe drinking water. Some methods are inadequate and expensive and some are low-cost. The BAMWSP has approved both the surface water and chemical options for mitigation purposes. In arsenic-contaminated areas, the easiest way to obtain safe drinking water is to find a nearby tubewell that has been tested and found to be safe. People in highly arsenic-contaminated areas can use water from dug-wells which are reported to be arsenic-free and pathogen-free as well as quite low iron concentrations (Chakraborti, 2001 and UNICEF, 2000). People have come to know that arsenic-free drinking water is available from deep tubewells and they are not motivated to take any preventive measures except deep tubewells.

Rainwater harvesting has been recommended by both the BAMWSP and the UNICEF. Since Bangladesh has a monsoon climate, people can preserve rainwater during the rainy season (June to September) for the dry months. Drinking boiled surface water rather than arsenic-contaminated tubewell water is also an important potential measure to prevent arsenic poisoning. Not all of the people are interested to drink boiled water and poor people cannot afford firewood for boiling it. In addition, reflexive sedimentation technology can be used to prevent arsenic poisoning. Apart from these, several low-cost technological options, i.e. water filtrations with the three-pitcher (3-kolsi) system, PSF, water-purification tablets, bucket treatments, Safi filter, alcan, garnet, steven etc, are important for removing arsenic from drinking water. But, most people in the study area cannot afford any of these systems.

Different organisations different roles: Various organisations are active on arsenic issues to different extents. Some NGOs are playing contributory roles in arsenic mitigation in providing arsenic-free tubewells and low-cost household or community-based arsenic removal technologies to their association members through their micro-credit programme. However, many NGOs are allegedly using arsenicosis patients for their own interests - they are earning money from donor agencies and using victims in the name of so-called laboratory tests (Haq, 2000) and mitigation. The DPHE has been instrumental in a number of large and small-scale arsenic mitigation initiatives. But the people are not happy with DPHE activities concerning deep tubewells. In some cases the DPHE has collected TK5000 in place of TK4500 for a deep tubewell, but nothing has happened for 2-3 years.

When people get sick, they first go to a doctor. Village doctors are not aware about arsenicosis except for a few and they provide arsenic-affected patients with the wrong prescription. They confuse arsenicosis with the other cases of sores on palms and soles. No curative medicines have yet been invented for arsenicosis and that doctors' prescribing practices are therefore flawed.

The government has taken various measures to mitigate arsenic poisoning, but these have been inadequate. The government has the tendency to blame its predecessors for not doing anything substantive in any regard and vice-versa. Since arsenic is a national problem, the government did not take the issue seriously enough after the first detection of arsenic concentrations in groundwater in 1993.

8.3 WHAT IS NEW IN THIS THESIS?

The thesis aims to identify the impact of arsenic poisoning on human health and social issues while generating new concepts using a multi-method approach. I have combined the use of spatial, quantitative and qualitative methodologies to understand the impact of arsenic on health and social issues as well as toxic-hazardous nature of arsenic in the study area. The use of a multi-method approach illustrates more about the combined patterns and processes of patient actions in dealing with illness and social problems than qualitative or quantitative studies undertaken alone.

The research questions in this thesis are exploratory and the information provided by the local people regarding their health and social problems caused by arsenic poisoning is multi-layered. The main aim of the research is to produce in-depth and holistic approaches for sufficient contextual and environmental conceptual applicability to generate a new concept, which is completely grounded in data. The multi-method approach increases the reliability and validity of the research outcome.

Through the grounded theory process, a core variable is identified which recurs frequently in the data, links the data together, and explains most of the variation in the data (Sherman and Webb, 1988). By relating this core variable to the various levels of codes already identified, the critical factors emerge and provide the new concept (Kerlin, 1998). The grounded theory provides the structure of the realities of situation with flexibility and rigour (Pickard, 1998).

By integrating spatial and statistical analytical methods I identified the 'problem regions' of the study area, and I used qualitative research to analyse the pain of arsenicosis patients. The spatial and statistical methods in combination justified the pattern of spatial distribution of arsenic concentrations in the study area and the pattern of spatial risk zoning. This thesis reveals the exposure to arsenic and its effects on human health and their inherent social problems, the survival strategies of affected people in the form of coping and adapting strategies, and the attitude on different levels of people towards the patients. It has also explored the experience of living in a society with arsenicosis, which involves living with social uncertainty, social injustice, social isolation and problematic family issues.

In reviewing the literature, there is a focus on arsenic toxicity in the form of the symptoms of arsenicosis at different levels, rather than on the pain that arsenicosis patients are recognising. The rationale and effectiveness of qualitative research have provided insights into the lay understandings about arsenic, its toxic effects on health and social effects, and how they manage their regular lives when affected with arsenicosis.

8.4 TRUSTWORTHINESS of the RESEARCH FINDINGS

Generally, qualitative studies are criticised because of their lack of rigour and credibility (Baxter and Eyles, 1997 and Decrop, 1999). Scientific rigour is necessary for any research method to understand and accurately represent the phenomena it studies (Rich and Ginsburg, 1999). Thus, validity and reliability are important considerations in qualitative research. Positivistic notions of validity and reliability cannot be applied in the same way to qualitative research.

In qualitative research, the conceptual meaning of validity may be applied by asking - are the methods relevant for the aims and objectives and the research questions? Or, to what contexts are the findings transferable? Such questions relate to the trustworthiness of the research findings. Trustworthiness summarises criteria for evaluating qualitative studies (Bunne, 1999; Crabtree and Miller, 1992; Denzin and Lincoln, 1994; Elder and Miller, 1995; Hamberg *et al*, 1994; and Lincoln, 1995). The following criteria are important to qualify trustworthiness of the thesis (Lincoln and Guba, 1985):

(a) Internal validity (credibility) – how truthful the particular findings are?

(b) External validity (transferability) – how applicable the research findings are to another setting or group?

(c) Reliability (dependability) – are the results consistent and reproducible? and

(d) Objectivity (confirmability) – how neutral are the findings?

Through the use of constant comparison process of grounded theory, I continually adjusted my data analysis to ensure (a) the degree of fit of data; (b) its functionality; and (c) relevance to the emerging theory.

(a) **The degree of fit** means categories are applicable to the research setting and directly derived from my collected data. Since the categories are generated directly from the collected data, the criteria of fit are automatically met (Sherman and Webb, 1988).

(b) **Functionality** refers to the ability of findings to explain the actions under study, i.e. for describing a theory that 'works' (Kerlin, 1998). Functionality explained the variation in the data and interrelationships among the constructs in a way that produced a predictive element to the new concept.

(c) **Relevance** means the core categories are meaningfully relevant to the research setting (Spaulding, 2000). Relevance evolves through the emergence of a core variable from the data in a way of my theoretical sensitivity to the arsenic milieu. Relevance is verified through the recognition in the study of the importance of the phenomenon (Sherman and Webb, 1988).

The concepts of degree of fit, functionality, and relevance are essential criteria for judging whether this study can be considered grounded and is therefore credible (Glaser and Strauss, 1967). In addition to the degree of fit, functionality, and relevance, I have used triangulation criteria to promote the credibility of this thesis. Triangulation reduces methodological biases and enhances credibility of this thesis. Triangulation is the use of multiple sources of data, multiple settings, and multiple methods to explain the research findings (Lincoln and Guba, 1985) as well as to cross-check (White and Taket, 1997).

(a) **Data triangulation** involves the use of a variety of data sources. Spatial, quantitative and qualitative data from both the primary and secondary sources were used for this thesis.

(b) **Method triangulation** for data collection entails the use of multiple-methods to collect relevant information for a single problem. Participant observation, in-depth interviews, focus-group discussions, informal and dialectic interviews were used as the method triangulation for the primary data collection; while the secondary data were collected from relevant literature and different documents (e.g. textbooks, newspaper, photographs, videos, etc).

(c) **Theoretical triangulation** involves using multiple perspectives to interpret a single set of data (Decrop, 1999). Spatial, quantitative, and qualitative methods as well as a combination of both were used in this thesis to build a new concept concerning arsenic-induced health and social hazard.

8.5 RECOMMENDATIONS

Considering the functionality and utility of spatial, quantitative and qualitative research in monitoring spatial arsenic magnitudes and its impact on human health and social hazards as well as various policy options for arsenic mitigation, several recommendations can be made.

8.5.1 Methodological

From the discussion of the pattern of arsenic concentrations in the space-time dimension, arsenic and depth relationships and spatial risk pattern, it is pointed out that GIS have the analytical capability to produce spatial outcomes, although it has little projective capacity for future planning. In addition, qualitative data collection procedures and the textual data analysis methods provide information of the inherent health and social problems of arsenicosis patients. From the methodological context, we can view some associated issues.

Spatial and Quantitative:

(a) GIS works in absolute and concrete space (Ottens, 1990). Spatial arsenic risk zones in the thesis operate at the intersection of spatial and attribute spaces. The exposure and toxicity assessment is always changing and the assessment is stated in terms of likelihood with uncertainties. In such cases, it was difficult for mapping the "spatial problem regions" with relation to the intangible tabular space through GIS.

(b) The existing GIS analytical techniques provide data systems rather than information for policy making. The systems can synthesise and integrate spatial data effectively, but have little capacity to forecast future patterns of arsenic poisoning. Moreover, GIS have no 'internal evaluative capability' (Brail, 1989) in proper spatial planning for spatial risk zones.

(c) I have identified that the BUFFER overlay technique in GIS is not suitable to identify the spatial risk zones in the study area because of its limited geometric measurement. In measuring buffer distance, different line and point features with different distance values were calculated and the values are fixed for some tubewells. But, practically, all the tubewells do not have the same command areas. These buffer distances are not a perfect system because of the various local factors such as availability of water all the year round, tubewell location, settlement pattern etc.

(d) Geostatistical techniques are suitable in producing thematic maps to define the pattern of spatial arsenic magnitudes by generating isolines. Spatial arsenic concentrations maps were produced by spatial interpolation methods in terms of IDW, RBF and OK methods. These methods provide different outcomes (Figures 4.6 and 4.7), in which the key issue is "which method is appropriate for the reality"?

(e) The PGIS techniques has been the dominating issue for identifying suitable sites for installing additional deep tubewells in the study area for a mitigation option. Many focus-group participants pointed out different possible sites for additional deep tubewells for obtaining arsenic-free water. Considering the people's perceptions on this issue, i.e. threshold distance, population size, number of households, area of neighbourhood, and schools and *madrashas*, I found that six to thirteen additional deep tubewells will cover the unserved areas, but using GIS techniques and following the threshold population, population size, and buffer distance of a deep tubewell, I calculated a need for an additional 23 deep tubewells for the unserved population of the study area. In view of the PGIS planning, there are some unserved and overlapping areas within the settlement zones when using half a kilometre buffer distance. On the other hand, a very few scattered unserved settlement areas result from the scenario based on GIS planning (Figure 7.13).

Qualitative:

(a) It has been observed from the study that qualitative methodologies in some cases have failed to understand the complexities of the socio-economic and cultural contexts in which indigenous livelihoods function (Kyei, 2000). During my field survey, I have found that most of the rural people confused arsenic with iron and some people failed to provide accurate responses on the socio-cultural context.

(b) Qualitative research in recent years has experienced a 'crisis of representation' (Declercq, 2000). The in-depth interview methods do not yield accurate responses since the respondent-interviewer relationship is too formal. In this way, it is not possible to get inherent information from a respondent. The database limitation makes the outcome a 'crisis of representation'.

(c) From some methodological points of view, PRA can be criticised as a "hasty and superficial approach as short-cut social science" (Cornwall and Fleming, 1995). In getting the general and quick view of arsenic situation in my study area, the PRA has proved to be unique. Used to generate 'short-cut' outcomes, PRA is no substitute for in-depth analysis (Cornwall and Fleming, 1995) or focus-group discussions and formal dialogues. It is noted that without careful scheduling of PRA sessions, the voices of the vulnerable sectors of society are easily missed (Arasu, 1997).

(d) A major problem when reading the grounded theory literature is a lack of clarity about key terms such as codes, theoretical codes, categories, theoretical categories, concepts, conceptual frameworks, theoretical sampling, etc. Different authors seem to engage in unnecessary jargon for labelling different aspects of the methodology (Lonkila, 1995). The main problem with grounded theory is how it glides and glosses over its ontological and epistemological assumptions.

8.5.2 Policy development

In mitigating arsenic poisoning, we need to consider many aspects in terms of socio-economic and socio-cultural aspects for proper policy. The short-term policies are not complementary for the long-term, thus both the short-term and long-term policies can be considered on an urgent and sustainable basis.

Short-term:

(a) There are some low-cost arsenic removal technologies available, but the problem is frequent use. Some poor people would not use these technologies since they cannot afford them. On the other hand, some people would not like to adopt these unfamiliar options, when they are fully adapted to the tubewell culture. In addition, in rural areas, people are not habituated with buying water and they have the feeling that water is a free-gift of nature. As there is no adequate alternative to get arsenic-free water, rural people are forced to use arsenic contaminated water. If alternative measures are not taken immediately many more people will be affected with arsenicosis in the near future, and the government could prepare some ponds in arsenic contaminated areas as reservoirs on an urgent basis for people to boil the water or otherwise purify.

(b) The thesis shows that decades ago, people used to drink and cook with pond water and there was a tradition to employ a particular pond only for drinking and cooking rather than any activities that might contaminate that pond water. In severely arsenic-affected areas where there are no alternatives, people *should switch* back from their present tubewell dependence to their previous pond water culture as an emergency policy.

(c) The awareness campaign is an important issue, as few people are conscious about arsenic contaminated water. Some NGOs along with the government have undertaken massive programmes to make people conscious about arsenic poisoning (UNB/NFB: 05/06/01, Bangladesh). But, most of them are not suitable since most of the people in rural Bangladesh cannot read newspapers and they cannot afford TV or radio. Thus it needs to rearrange awareness campaign in rural Bangladesh following the techniques investigated in Chapter - VII.

(d) Children can easily come to know about arsenic and related issues if it is included in the academic curriculum, just as population problems, floods, cyclones, etc have already been included in different academic curricula for permanent proliferation.

(e) The arrangement of short training courses for different working groups would be productive. After receiving training on arsenic issues, they could subsequently contribute to the arsenic awareness campaign as well as to arsenic preventive measures.

Long-term:

(a) I have discussed the utility and suitability of different preventive measures and low cost technologies for arsenic mitigation. But, environmentally supportive natural mitigation options could also be helpful. Bangladesh is a riverine country and her huge surface water sources in terms of closed and open water bodies could be used for irrigation rather than the use of groundwater. Apart from this, if there is any shortage of surface water for irrigation, it is possible to use river water flowing through connecting canals with the nearby main rivers. The "canal excavation policy" for irrigation could avert groundwater arsenic poisoning in soils and the food chain. The proper excavation of canals could lead to the appropriate use of surface water for irrigation.

(b) The oxidation hypothesis proved that heavy withdrawal of groundwater for irrigation leads arsenic into the groundwater. Canals and many closed water bodies are available in Bangladesh and it is possible to provide water for the *Rabi* crop from the surface water sources rather than groundwater. The literature shows that arsenic can enter the food chain when groundwater is used for irrigation (Dabeka *et al*, 1993; Gunderson, 1995; Chowdhury *et al*, 2002; and Tsuda *et al*, 1995) and arsenic-contaminated dietary staples may have substantially contributed to exposure and adverse health effects (Schoof *et al*, 1998). If the government formulates a policy to remove arsenic from groundwater but not stopping its use for irrigation, in long-run, this will be environmentally disastrous.

(c) In Bangladesh, before the advent of tubewells, people used surface water that was contaminated with micro-organisms, but they are now habituated to the tubewell culture. Many find it difficult to shift back to the past habit that has been altered over three decades. It is essential in this regard to make a policy to increase awareness and influence people to use pond water by either boiling it or purify it with a filter. But the problem during the dry months is that most of the tubewells remain dry and no water is available in most of the ponds due to mechanised extraction for irrigation. Therefore, for surface water to be available all the year round, there needs to be a policy to stop pumping groundwater for irrigation. It is not possible to do it instantly.

(d) In Bangladesh, many towns and cities including Satkhira Municipality have arsenic-free piped water systems. Although it sounds ambitious for the government to set up new pump and treatment plants for the *union* level water supply system, it would meet the arsenic-free drinking water demands for the people of the rural areas beyond the municipalities. Although this would be costly, the government could begin planning this mitigation as a long-term option. To develop a piped-water supply system, they should keep in mind the clustered form of rural settlement in Bangladesh where it is difficult to arrange supply water systems to the rural areas.

(e) An alternative to piped-water system for rural areas is the plan for some sectoral reservoirs and piped water-supply systems at points where people could collect arsenic-free water. Treated water can be stored in reservoirs at some point of optimum distance from users and then supply this water through a piped-system to each settlement cluster or community for easy access from a stand pipe.

(f) The deposition of arsenic sludge is a serous threat to environment. The unplanned disposal of highly toxic arsenic sludge could contaminate nearby waterways and can infiltrate into groundwater. Thus, the arsenic problem can best be tackled by the alternative of treating surface water rather than groundwater.

(g) The thesis shows that almost all of the shallow tubewells and some of the deep tubewells are arsenic contaminated. Mandal *et al* (1996) found that in 1990, the Public Health Engineering Department of India installed deep tubewells to deeper depths (150 metres) in Nadia, where the shallow aquifer was found to be arsenic contaminated. At the beginning, arsenic was not found in deep tubewells but in the course of time all of these deep tubewells have become contaminated. The government should therefore seriously consider a policy to stop the fresh installation of all tubewells.

Future research:

(a) Almost all of the studies reported in the literature have explored selected aspects of living with arsenicosis. But most studies have used quantitative methods of data collection and have involved mainly the identification of patients and the identification of safe and contaminated tube wells. The qualitative methodology from a geographical point of view would be novel in analysing the geographical problems we have identified.

(b) It has been found that individuals may respond to chronic arsenicosis in a similar fashion, regardless of differences in treatment. Future research is needed to examine potential differences in response to chronic arsenicosis based on age and gender undetected in this study.

(c) In view of the problems associated with buffer generations in identifying the spatial risk zones, it may be suggested that there needs to be further research on BUFFER and its geometrical measurements as well as on different geostatistical methods. It should also be discussed whether a manual buffer distance can be established or not, other than the geometric buffer distance. Which interpolation method is suitable, is a concern for future research.

8.6 CONCLUDING REMARKS

This thesis has examined the capability and functionality of GIS methods, especially the GIS OVERLAY operations and BUFFER techniques in analysing 'spatial risk zoning'. Geostatistical approaches were used for spatial interpolation of arsenic concentrations and the GLMs have been established as a useful technique for analysing the quantitative data for this research. In addition, qualitative methodological approaches were explored for aptitude and functionality in identifying the health and inherent social issues of the arsenicosis patients. From the overall discussion, it may be noted that the multi-method approaches adopted in this thesis have been demonstrated and justified as excellent tools to handle a wide range of quantitative and verbatim databases in a meaningful form.

Quantitative analysis shows the overall arsenic magnitude and its effects on health, with numbers of people affected with arsenicosis, rather than the inherent health and social problems that the affected people are experiencing. This thesis has explored the health situations and the social problems of people during their illness. The qualitative data have enabled a complex understanding of how poor arsenic-affected people perceive their social situation and the factors influencing it. In view of the overall thesis, it has seen that people's perceptions of their health and social problems caused by arsenicosis indicate worse health and social situations than they have ever faced before. This situation by arsenic toxicity is considered to be a 'natural hazardous condition' of major proportions in Bangladesh.

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APPENDICES

APPENDIX - A

GIS DATA LAYERS
[Feature Identification File]

1. Line (ARC) Information

1000: **Map Boundary**
1001: International Boundary
1002: Divisional Boundary
1003: District Boundary
1004: Thana/Upazila Boundary
1005: Union Boundary
1006: Mauza Boundary
1007: Ward Boundary
1008: Mauza Sheet Boundary
1009: Plot Boundary
1010: Municipality/Pauroshava Boundary
1011: Coastal Boundary

1500: **River Information**
1501: Large Rivers (Polygon-1:5000 map)
1502: Small Rivers (Line)
1503: Khal or Canals (Line)

1600: **Road Information**
1601: Main Roads (Polygon - 1:5000 map)
1602: Main Roads (Line Information)
1603: National/Regional Highway
1604: Feeder Road (Type – A)
1605: Feeder Road: Inter-union (Type – B: Metalled)
1606: Feeder Road: Inter-union (Type – B: Herring Bond)
1607: Feeder Road: Inter-union (Type – B: Earthen)
1608: Paurashava Road (Type – R1: Metalled)
1609: Paurashava Road (Type – R1: Herring Bond)
1610: Paurashava Road (Type – R1: Earthen)
1611: Local Road (Type – R2: Metalled)
1612: Local Road (Type – R2: Herring Bond)
1613: Local Road (Type – R2: Earthen)
1614: Rural Road (Type – R3: Metalled)
1615: Rural Road (Type – R3: Herring Bond)
1616: Rural Road (Type – R3: Earthern)

1700: **Railway Information**
1701: Railway Lines with Station (Broad Gauge)
1702: Railway Lines with Station (Metre Gauge)

1800: **Service Information**
1801: Telephone Line
1802: Electricity Line

1900: Underground Service Information
1901: Telephone Line
1902: Electricity Line
1903: Gas Line
1904: Sewerage

2. Polygon Information

2000: **Settlement Area**
2001: Settlement Area
2002: Pucca house
2003: Kutcha house

2100: **Agricultural Land**
2101: Homestead Agricultural

2200: ***Point Like Polygon***
2201: University
2202: College
2203: High School
2204: Primary School
2205: Nursery or Kinder Garden School
2206: Madrasa
2211: Eidgaah
2212: Graveyard
2221: Family Planning Centre

3. Point Information

3000: **Headquarters**
3001: Capital
3002: Divisional Headquarters
3003: District Headquarters
3004: Thana/Upazila Headquarters
3005: Union Parishad (UP) Office

3100: **Commercial Areas**
3101: Growth Centre
3102: Trading Centre
3103: Bazzar (Regular)
3104: Hat (Regular)
3105: Hat (Periodical)

3200: **Services**
3201: Hospital
3202: Thana/Upazila Health Complex
3203: Family Planning Centre
3204: Community Health Clinic
3205: Private Clinic
3206: Bank
3207: Post Office
3208: Telephone/Telegraph Office
3209: Mill/Factory
3210: BRAC Office

3300: **Education**
3301: University
3302: College
3303: High School
3304: Primary School
3305: Madrasa

3400: **Religions**
3401: Mosque
3402: Eidgaah
3403: Temple
3404: Church
3405: Graveyard
3406: Cremation point

APPENDIX - B

SURVEY DATA SHEET
[ARSENIC RESEARCH]
(Tubewell Screening and Relevant Information)

Sheet No	
Date	00/00/01

1. Survey area name and code (Ghona Union)

Mouza			Village			Para		

2. Tube well information

Well_ID	Plot No.	Ownership	Installation	Depth (ft)	Well type	Users	As (mg/l)
		1 2 3 4 5	E: B:		1 2 3		

1: Private, 2: Community, 3: Govt, 4: NGOs, and 5: Others

1: STW, 2: DTW, and 3: Tara.

3. Household (HH) and health information (well holder only)

	Family members			Education						Occupation					Income	Patients (visible)		
	Name	M_age	F_age	1	2	3	4	5	6	*1*	*2*	*3*	*4*	*5*	(Yearly)	Low	Med	High
H																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		

1: No Education, 2: Primary, 3: Secondary, 4: Higher secondary, 5: Graduation & 6: Others. *1: Agriculture, 2: Business, 3: Service, 4: Informal, and 5: Others.*

4. Social problems (patients only – if any)

	Problems									Consultation						Open-ended questions: Death due to arsenicosis? If yes, when identified? Other problems? HH head's perceptions etc,.
	1	2	3	4	5	6	7	8	9	*0*	*1*	*2*	*3*	*4*	*5*	
H																
2																
3																
4																
5																
6																
7																
8																
9																
0																

1: Conjugal life, 2: Divorce, 3: Separation, 4: Forcibly sent to the parental home, 5: Neglect by the f_members, 6: Not at school, 7: Not offered a job, 8: Barred from social activities, and 9: Others.

0: No, 1: Doctor, 2: NGO, 3: DPHE, 4: Traditional, & 5: Others.

5. Mitigation and others (HH_Head only)

Emergency water supply needs			Mitigation type (if done)					Mitigation done (by whom)?				
1: Yes	2: No	3: Already have	1	2	3	4	5: Others	0: None	1: Private	2: Govt	3: NGO	4: Others

1: Surface water treatment, 2: Rainwater harvesting, 3: Bucket, 4: Arsenic-free tube well, 5: Others.

6. Alternative sources of drinking water

1: STW	2: DTW	3: Pond	4: Khal (Canal)	5: River	6: Others

7. Remarks

APPENDIX - C

DATA SHEET
(Arsenic Research)
[Tubewell Information]

Name and Sign

সিরিয়াল (Serial)	মালিকের নাম (Tubewell Holder)	মৌজা (Mauza)	ওয়ার্ড (Ward)	গ্রাম (Village)	পাড়া (Para)	বসানোর সাল (Inst. year)	গভীরতা (Depth, f)	দাগ নং (Plot)

APPENDIX - D

IN-DEPTH INTERVIEW SCHEDULE
(Relevant Questions)

1. About yourself and your neighbourhood.

- Could you please tell me a little bit about yourself (e.g. your name, address, age, occupation, family members etc).
- How long have you been here (in this union or village) and where did you live before this?
- Is there anything that worries/concerns you about living here (arsenic issues)?

2. About arsenic, toxicity and risk.

- What do you know about arsenic? How have you come to know about it? Do you think arsenic issues are important or problems? Why?
- What do you think about toxicity? Do you think arsenic is toxic element? Why? How do you know about this?
- What do you know about floods, cyclones etc? Do you think the drinking water from your tube well is safe or is it risky to drink that water?
- Do you personally feel threatened by risk from arsenic toxicity? In what ways?
- Do you think arsenic is a problem in your union or village as a whole? Explain. Which areas, do you think are affected by arsenic (low to severe and show him a simple map and ask him to **draw** the areas on that map)?
- What do you think is the main causes of arsenic? How do you know? Who is responsible in cases of arsenic occurrence? Why?

3. About arsenic-related diseases and health issues.

- How would you know about good health? Do you think health can be affected by arsenic? Or, do you think some illnesses in particular are affected by arsenic? Explain. How have you come to know about the health effect of arsenic?
- Have you experienced any arsenic related disease? What are the symptoms?
- How often do you experience illness? When have you come to know that you are affected with arsenic? Has it got better or worse over the years?
- Is any member of your family suffering from arsenic related diseases? How many and how long?
- Do you take any measures to avoid arsenic toxicity? What? Do you or have you go/gone to doctors (GP) or NGOs or Government health workers for treatment? What they told you about the disease or illness? Whether do they provide you any medicine or advice? What?
- Do you know of anyone else who suffers from a similar problem round here?

4. About social problems and hazards

- Do you think arsenic toxicity creates social problems? If yes, what types of problems?
- Do you or any of your family member(s) face any social problems when people in your area know that you are affected with arsenocosis? What type of problems? Explain.
- When did you or your family members first face the social problems? How do you manage your social life when you and your family members facing the problems?
- Do you think NGOs, DPHE, Government organisation, local administration or other organisations are helping you? If yes, how? If not, what do you think about their activities?
- Do you think there is anything can be done to reduce the social problems? If yes, what? Or, anything you personally can do? What?

5. About mitigation and policy.

- What do you think about arsenic awareness campaigning?
- Have you seen or heard anything in the media (television, radio, newspaper etc) about arsenic poisoning? What do you think about that?
- Anybody from NGO, DPHE or other organisations visited you regarding arsenic and related issues? If yes, why? What they told or did for you?
- What do you think about the arsenic mitigation? Do you think anything could be done for arsenic mitigation? If yes, what and how? If no, why not?
- Whose responsibility is it to mitigate arsenic in your area? Or, whose responsibility is to provide safe drinking water - DPHE or Local NGOs or Municipality? Why?
- Do you think individuals can do anything to reduce arsenic from drinking water? If yes, in what ways? If no, why not?

APPENDIX - E

FOCUS-GROUPS DISCUSSION SCHEDULE
(Relevant Questions)

- What comes to mind when you hear about arsenic toxicity?

  Key words: Poison, Pollution, Contaminated drinking water, Environmental health risk, and Social incidence?

- How have you known about the toxicity of arsenic?

  Key words: Media (Radio, Television, Newspapers), Local NGO, Government offices?

- Do you think arsenic toxicity affects health?

  Key words: Melanosis, Keratosis, Hyperkeratosis, Diabetes, Gangrene and Cancer?

- How do you manage your daily activities when you and or your family members affected with arsenic related diseases? Or, is anyone helping you?

  Key words: Doctors (GP), DPHE, NGOs, Government organisations, Local administrations etc.

- Do you know about the effects of arsenic in family life and social life?

  Key words: Conjugal life, Divorce, Separation, Problems in getting married for young unmarried women, Problems in getting jobs, Socially isolation etc,?

- Do you know who are the responsible authorities in mitigating the arsenic toxicity and how?

  Key words: Local elected administration (Union Porishad Chairman and Members as a part of local government), NGOs, and Government Organisations (DPHE, LGED, Municipality)?

- What do you think about the responsibility of Doctors, Health workers, NGOs, DPHE, Government organisations or others?

- Which areas of your locality are contaminated with arsenic or which tube wells are highly contaminated? [Here they will be provided simple maps with different landmarks for arsenic concentration].

APPENDIX – F (1)

ARSENIC DATA: WARD - 1, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst. Year	Depth (Metre)	Arsenic (mg/l)	Water Condition
101	Md. Adam Chobi	Gazipara	Government	389	40	350	1992	74	0.250	Available water
102	Md. Fazlur Rahman	Gazipara	Private	527	30	-	1993	83	0.261	A little bit water
103	Md. Solimuddin Gazi	Gazipara	Private	520	150	-	1996	40	0.300	No water
104	Md. Nurul Islam	Mollapara	Government	490	100	-	1975	46	0.353	A little bit water
105	Md. Kabirul Islam	Mollapara	Private	490	5	-	2000	98	0.303	No water
106	Md. Alauddin Gazi	Mathpara	Government	619	150	250	1995	52	0.350	Available water
107	Md. Abdur Razzaque	Gazipara	NGO	461	200	-	2000	74	0.346	No water
108	Ghona Pacchimpara Zame Mosque	Pacchimpara	Government	480	20	-	1998	40	0.314	No water
109	Md. Abdul Khaleque	Parrpara	Private	546	70	-	1995	57	0.119	A little bit water
110	Md. Rabiul Islam	Mollapara	Private	588	40	-	1990	74	0.316	No water
111	Md. Tayeb Ali Sarder	Parrpara	Private	588	40	-	1989	60	0.309	No water
112	Md. Abdul Halim	Mollapara	Private	586	200	-	1992	57	0.319	A little bit water
113	Md. Lutfur Rahman	Mollapara	NGO	560	125	-	1999	55	0.310	A little bit water
114	Md. Abdul Muttalib	Mollapara	Private	561	100	-	1999	57	0.356	A little bit water
115	Md. Sohorab Hossain Gain	Gainpara	Private	684	50	-	1996	61	0.344	No water
116	Dr. Abdul Gafur	Gainpara	Private	743	100	-	1996	62	0.307	No water
117	Md. Abdul Karim Master	Gainpara	Government	754	175	-	1971	42	0.314	No water
118	Md. Nurul Islam	Gainpara	Private	766	40	-	1998	58	0.157	No water
119	Md. Abdur Rahim	Gainpara	Private	766	70	-	2000	94	0.300	No water
120	Md. Abdul Wahid	Gainpara	Government	806	60	-	1994	45	0.163	A little bit water
121	Md. Deldar Rahman	Gainpara	Private	943	40	200	1997	57	0.133	Available water
122	Md. Ziad Ali	Gainpara	Private	944	12	40	1997	74	0.283	A little bit water
123	Md. Manik Gain	Gainpara	Government	841	125	-	1985	18	0.096	No water
124	Md. Rajab Ali	Gainpara	Private	842	20	-	1999	74	0.103	No water
125	Gainpara Zame Mosque	Gainpara	Government	861	25	50	1983	42	0.150	Available water
126	Md. Wazed Ali Molla	Gainpara	Private	721	15	-	1994	65	0.130	No water
127	Md. Abdul Gaffar Molla	Gainpara	Private	732	50	-	1990	65	0.123	No water
128	Md. Zahir Uddin Sarder	Gainpara	Private	884	50	-	1996	58	0.187	A little bit water
129	Md. Golam Bari	Gainpara	Private	877	60	-	1996	58	0.270	No water
130	Md. Abdul Bari	Gainpara	Private	875	20	-	1998	58	0.215	No water
131	Md. Ibrahim	Gainpara	Private	874	15	150	1996	72	0.275	Available water
132	Md. Ibadat Hossain	Gainpara	Private	899	10	-	1988	57	0.138	No water
133	Md. Motiuur Rahman	Gainpara	Private	915	15	-	1992	42	0.222	No water
134	Md. Momtaz Ahmed	Gainpara	Private	917	15	-	1995	42	0.106	No water
135	Md. Ishak Karikor	Gainpara	Government	872	60	-	1983	42	0.144	No water
136	Md. Zasim Uddin	Gainpara	Private	926	6	-	1988	65	0.092	No water
137	Md. Deldar Hossain	Gainpara	Private	721	200	250	1997	78	0.241	Available water
138	Md. Ifaz Tullah Gazi	Gainpara	Private	1783	30	-	1998	42	0.261	No water

APPENDIX - F (2)

ARSENIC DATA: WARD - 2, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Condition
139	Md. Khalilur Rahman	Bashiapara	Government	1845	130	-	1983	42	0.034	No water
140	Md. Abdul Khayer	Bashiapara	Private	1869	70	-	1999	80	0.169	No water
141	Md. Nuruddin Sardar	Bashiapara	Government	1882	80	-	1995	52	0.140	A little bit water
142	Bashiapara A_Hadith Zame Mosque	Bashiapara	Government	1851	75	-	1990	74	0.069	No water
143	Hazi Abdur Rashid	Bashiapara	Government	1847	50	-	1983	42	0.043	No water
144	Md. Ziad Ali Hazra	Bashiapara	Private	1715	40	-	1995	60	0.324	No water
145	Md. Eunus Ali Sardar	Bashiapara	Private	1698	50	150	1994	74	0.280	Available water
146	Md. Abul Hossain	Bashiapara	Private	1713	60	-	1988	54	0.256	No water
147	Md. Khoda Bokso Beshe	Bashiapara	Private	1710	35	-	1974	65	0.232	No water
148	Md. Afsar Uddin	Bashiapara	Private	1960	150	-	1990	42	0.324	No water
149	Md. Rahil Uddin Beshe	Bashiapara	Private	2029	100	250	1985	78	0.314	A little bit water
150	Md. Hakim Beshe	Bashiapara	Private	1956	75	-	1998	49	0.205	No water
151	Md. Nurullah	Bashiapara	Government	1953	20	120	1983	42	0.195	Available water
152	Md. Shahidul Islam	Bashiapara	Private	1954	10	-	1997	65	0.232	No water
153	Md. Abdul Gafur	Bashiapara	Government	1887	100	-	1982	49	0.115	No water
154	Moulana Md. Abdullah	Bashiapara	Private	1934	50	-	1997	66	0.324	No water
155	Md. Auzihar Beshe	Bashiapara	Government	1897	75	-	1996	55	0.227	No water
156	Ghona Govt. Primary School	Bashiapara	Government	1933	250	-	1992	37	0.241	No water
157	Md. Mohsin Ali	Bashiapara	Government	3438	100	-	1983	42	0.179	No water
158	Md. Akbar Ali Gazi	Bashiapara	Government	3468	6	50	1988	42	0.266	Available water
159	Ghona Rahmania Dakhil Madrasa	Habrapara	Government	3526	125	300	1996	52	0.270	Available water
160	Sayed Ali Sardar	Habrapara	Private	3584	100	-	2000	45	0.241	No water
161	Md. Azizar Rahman	Haurpara	Government	3594	125	-	1980	42	0.134	No water
162	Md. Abul Kalam	Malpara	Private	3589	30	-	1987	68	0.083	No water
163	Kazipara Zame Mosque	Kazipara	Government	3661	150	-	1990	77	0.310	No water
164	Md. Golam Bari	Gazipara	Private	3660	50	-	1985	49	0.170	No water
165	Md. Nurul Islam Dofadar	Dofadarpara	Private	4015	125	300	1995	69	0.346	Available water
166	Md. Nazrul Islam Dofadar	Dofadarpara	Private	3663	35	-	1997	68	0.357	No water
167	Md. Wazed Ali Dofadar	Dofadarpara	Private	3668	50	-	1996	68	0.428	No water
168	Md. Intaz Ali Dofadar	Dofadarpara	Government	3672	55	-	1996	68	0.365	No water
169	Md. Sadek Ali Dofadar	Dofadarpara	Private	3705	10	-	1995	37	0.413	No water
170	Md. Aksed Ali Dofadar	Dofadarpara	Private	3705	7	-	1995	37	0.328	No water
171	Md. Moksed Ali Dofadar	Dofadarpara	Private	3705	16	-	1995	37	0.357	No water
172	Md. Mahtab Gazi	Gazipara	Government	3717	100	-	1983	42	0.353	A little bit water
173	Md. Lutfur Rahman	Gazipara	Private	3712	50	-	1995	74	0.283	No water
174	Md. Mofizur Rahman	Gazipara	Private	3718	200	350	1994	74	0.375	Available water
175	Ghona Camppara Moktab	Camppara	Government	3764	100	-	1996	42	0.309	No water
176	Md. Niamuddin Sardar	Camppara	Private	3758	50	-	1988	74	0.285	A little bit water
177	Md. Alfaz Sardar	Camppara	Private	3780	100	-	1998	52	0.339	No water
178	Md. Ruhul Kuddus	Camppara	Private	3779	50	-	1981	55	0.196	A little bit water
179	Md. Auhidul Dalal	Camppara	Government	3769	35	-	1983	42	0.256	No water
180	Md. Abdul Khaleque	Camppara	Private	3790	150	350	1985	138	0.227	No water
181	Ghona BDR Camp	Camppara	Government	3804	-	-	1983	42	0.375	No water
182	Md. Abdul Kashem	Camppara	Private	3747	100	-	1998	62	0.357	No water
183	Near WAPDA Embankment	Camppara	Government	633	200	200	1987	42	0.400	No water

APPENDIX - F (3)

ARSENIC DATA: WARD - 3, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Conditions
184	Md. Moktar Ali Sardar	Kazipara	Private	6612	15	-	1997	37	0.217	No water
185	Md. Anwar Hossain	Kazipara	Private	6616	30	-	1990	37	0.129	No water
186	Md. Atiuur Mistri	Kazipara	Private	6616	30	75	1997	80	0.283	Available water
187	Md. Islam Sheikh	Kazipara	Private	6625	40	-	1987	34	0.256	No water
188	Md. Abdur Rahim Kazi	Kazipara	Private	6629	50	-	1994	54	0.283	No water
189	Mustafa Kamal Ahsan	Kazipara	Govt.	6651	120	-	1990	80	0.304	No water
190	Md. Zaha Boskt Sardar	Kazipara	Private	6847	100	-	1992	28	0.285	No water
191	Md. Ahsan Ullah (Bablu)	Sardarpara	Private	6735	20	-	1988	46	0.366	No water
192	Md. Zamaluddin Sardar	Sardarpara	Private	8226	250	350	1999	168	0.008	Available water
193	Alhazz Yasin Ali	Karikorpara	Private	6573	35	-	1990	51	0.227	No water
194	Md. Masud Parvez	Karikorpara	Private	6573	30	-	1996	43	0.327	No water
195	Ghona Karikaorpara Zame Mosque	Karikorpara	Govt.	6552	60	-	2000	62	0.392	No water
196	Md. Anwar Hossain	Karikorpara	Private	6573	40	-	1996	97	0.357	No water
197	Md. Rabiul Islam	Karikorpara	Private	6552	35	-	1998	62	0.138	No water
198	Md. Sirajul Islam	Karikorpara	Private	6563	20	-	1995	68	0.448	No water
199	Sree Binoy Kirishna Mazumder	Majherpara	Govt.	6560	40	100	1983	42	0.057	Available water
200	Sree Zagodish Mazumder	Majherpara	Private	6565	15	-	1990	55	0.365	No water
201	Sree Nirmal Mazumder	Majherpara	Private	6568	10	-	1991	43	0.357	No water
202	Md. Monzel Gazi	Majherpara	Private	6215	70	-	1992	49	0.326	A little bit water
203	Kazipara Govt. Primary School	Kazipara	Govt.	6213	250	-	1982	52	0.283	No water
204	Ghona Majherpara Zame Mosque	Kazipara	Private	6208	60	-	1990	55	0.362	No water
205	Md. Omar Ali Sheikh	Majherpara	Private	6224	125	250	1995	82	0.410	Available water
206	Kazi Fazlur Rahman	Majherpara	Private	6198	75	-	1999	74	0.316	A little bit water
207	Md. Nesaruddin Kazi	Majherpara	Govt.	6198	100	-	1993	42	0.290	No water
208	Md. Moksed Ali Gazi	Majherpara	Govt.	6233	40	-	1992	45	0.280	No water
209	Md. Moktar Ali Baddya	Dewanpara	Private	6137	100	-	1996	55	0.346	A little bit water
210	Md. Mohsin Sardar	Sardarpara	Govt.	6191	50	125	1983	42	0.185	Available water
211	Sree Bashiram Das	Daspara	Private	3640	30	-	1996	85	0.357	No water
212	Md. Abubakar Siddique	Sardarpara	Govt.	6544	60	-	1983	42	0.324	No water
213	Sree Kalipado Pal	Palpara	Govt.	6501	25	-	1998	62	0.446	No water
214	Md. Ibrahim Khalil	Mathpara	Private	7547	100	-	1990	55	0.384	No water
215	Md. Rahim Uddin Gazi	Mathpara	Private	7151	20	-	1995	62	0.410	A little bit water
216	Maolana Munir Uddin Gazi	Mathpara	Private	7567	30	-	1995	49	0.375	No water
217	Md. Koshlal Gazi	Mathpara	Private	7570	25	-	1995	49	0.423	No water
218	Md. Deldar Gazi	Mathpara	Private	7569	20	-	1992	43	0.450	A little bit water
219	Mathpara Zame Mosque	Mathpara	Govt.	6452	100	-	1992	49	0.400	No water
220	Md. Nazrul Islam	Mathpara	Private	6440	50	-	1990	68	0.383	No water
221	Md. Showkat Ali	Mathpara	Govt.	6459	40	-	1983	49	0.446	No water
222	Md. Zahangir Alam	Ghozerdangi	Govt.	2936	50	-	1995	45	0.346	No water

APPENDIX - F (4)

ARSENIC DATA: WARD - 4 GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Conditions
223	Md. Roichh Molla	Hatkhola	Private	6550	5	-	1980	49	0.111	No water
224	Md. Zamat Ali	Hatkhola	Private	6549	7	20	1995	62	0.375	Available water
225	Md. Rafiqul Islam	Hatkhola	Private	7374	15	-	1990	40	0.379	No water
226	Md. Manik Molla	Hatkhola	Private	7372	25	40	1988	40	0.329	Available water
227	Sree Bimal Kirishna Pal	Palpara	Govt.	7376	20	-	1983	42	0.413	No water
228	Ghona Health Complex	Hatkhola	Govt.	7397	300	600	1998	180	0.061	Available water
229	Ghona Hatkhola	Hatkhola	Govt.	7401	100	-	1995	42	0.312	No water
230	Md. Shariful Islam	Hatkhola	Private	7405	10	-	1994	60	0.339	A little bit water
231	Md. Rafiqul Islam Sardar	Hatkhola	Private	7405	7	-	1992	52	0.375	No water
232	Md. Abdud Gani Dalal	Hatkhola	Private	7402	30	-	1990	68	0.101	No water
233	Md. Nurul Amin	Hatkhola	Private	8273	20	-	1995	74	0.145	A little bit water
234	Sree Hazari Biswas	Poramanik	Govt.	7349	60	-	1992	55	0.037	No water
235	Md. Abul Kashem	Purbapara	Private	7356	10	-	1976	55	0.096	A little bit water
236	Md. Abdur Raquib	Karikorpara	Private	8040	35	-	1991	62	0.080	No water
237	Md. Momrez Molla	Purbapara	Private	8038	10	-	1992	62	0.188	No water
238	Md. Mizanur Rahman Master	Purbapara	Private	8033	30	-	1995	49	0.217	A little bit water
239	Md. Nazrul Islam	Purbapara	Private	8026	60	150	1998	77	0.410	Available water
240	Ghona Purbapara Zame Mosque	Purbapara	Govt.	7992	125	-	1999	80	0.290	No water
241	Md. Korban Ali Sardar	Purbapara	Private	8011	250	450	1995	180	0.012	Available water
242	Md. Abdur Razzaque	Purbapara	Private	8010	6	-	1992	74	0.178	A little bit water
243	Md. Emdad Sardar	Purbapara	Private	8009	8	-	1992	74	0.189	No water
244	Md. Hazrat Ali	Purbapara	Private	8009	30	-	1989	74	0.196	No water
245	Md. Shahadat Sardar	Purbapara	Private	8010	40	-	1997	74	0.142	A little bit water
246	Md. Rostam Ali	Purbapara	Private	8006	10	-	1985	49	0.295	No water
247	Md. Mofizul Islam	Purbapara	Private	8006	20	-	1994	49	0.261	No water
248	Md. Soharaf Sardar	Purbapara	Private	8024	15	-	1997	74	0.142	No water
249	Md. Ainal Golder	Purbapara	Private	8025	10	-	1985	74	0.146	No water
250	Md. Raju Golder	Purbapara	Govt.	8013	20	-	1996	74	0.151	A little bit water
251	Md. Assadul Faruque	Karikorpara	Private	7314	75	-	1985	40	0.339	No water
252	Md. Khadem Gazi	Sreedanga	Private	8062	50	-	1991	80	0.280	A little bit water
253	Md. Shukoor Ali	Sreedanga	Private	8062	15	-	2000	62	0.232	No water
254	Md. Ishaq Sardar	Sreedanga	Govt.	8065	75	-	1983	42	0.280	No water
255	Dr. Bimal Kirishna Mondal	Sreedanga	Govt.	8084	70	-	1979	42	0.105	A little bit water
256	Sree Rakhal Chandra Mondal	Sreedanga	Private	8084	20	-	1990	62	0.187	No water
257	Md. Sayed Ali Sardar	Sreedanga	Private	8115	50	-	1997	53	0.375	No water
258	Sreedangi Zame Mosque	Sreedanga	Govt.	8115	150	-	1982	46	0.285	No water
259	Md. Solim Sardar	Sreedanga	Private	8126	100	-	1996	49	0.264	No water
260	Md. Auyub Sardar	Sreedanga	Private	8121	25	-	1990	52	0.223	No water
261	Mohammad Ali	Sreedanga	Private	8129	150	350	1997	180	0.023	Available water
262	Sreedangi Madrasa	Sreedanga	Private	8132	60	-	1981	58	0.256	No water
263	Md. Fazlul Haque (Rice Mill)	Sreedanga	Private	8132	20	-	1988	74	0.392	No water
264	Md. Abdul Gaffar	Sreedanga	Private	7246	60	-	1998	52	0.355	A little bit water
265	Dr. Abdul Khaleque	Sreedanga	Private	8148	15	-	1975	48	0.069	No water
266	Md. Rezaul Karim	Sreedanga	Private	7232	25	-	1994	49	0.270	No water
267	Dr. Abdur Rashid	Sreedanga	Private	7246	40	-	1998	62	0.357	No water
268	Md. Shahidul Islam Sheikh	Sreedanga	Private	7275	25	-	1993	62	0.375	A little bit water
269	Md. Abdar Rahman Dhali	Sreedanga	Govt.	7272	75	125	1995	80	0.214	Available water
270	Md. Aatiuur Rahman	Sreedanga	Private	7203	100	-	1993	58	0.130	No water
271	Md. Asir Uddin Sardar	Sreedanga	Private	7189	70	-	1985	58	0.357	No water
272	Md. Asir Uddin Sardar	Sreedanga	Private	7189	15	-	1996	58	0.410	A little bit water
273	Md. Abdul Karim Sardar	Sreedanga	Private	7183	50	-	1984	49	0.333	No water
274	Md. Shahidul Islam	Sreedanga	Private	7186	20	-	1996	54	0.333	A little bit water
275	Md. Shamsur Rahman	Sreedanga	Private	7184	70	-	1990	55	0.275	No water

APPENDIX - F (5)

ARSENIC DATA: WARD - 5, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Conditions
276	Sree Kartik Chandra Das	Reeshipara	Private	756	100	-	1998	52	0.128	No water
277	Chanka Bazzar	Chanka Bazzar	Govt.	594	150	-	1987	46	0.142	No water
278	Md. Khorshed Alam	Sardarpara	Private	595	50	-	1998	55	0.123	No water
279	Md. Kala Chand Sardar	Sardarpara	Private	598	60	-	1990	52	0.133	No water
280	Md. Ishak Ali	Mredhapara	Private	607	40	-	1993	66	0.178	No water
281	Md. Habibur Rahman	Mredhapara	Private	607	50	-	1996	52	0.138	No water
282	Md. Khairul Islam	Mredhapara	Private	606	10	-	1997	55	0.251	No water
283	Chanka Govt. Primary School	Chanka Bazzar	Govt.	565	150	-	1982	52	0.181	No water
284	Ghona High School	Chanka Bazzar	Govt.	567	450	-	1970	55	0.130	No water
285	Sree Auvilash Ghosh	Ghoshpara	Govt.	520	75	200	1995	42	0.169	Available water
286	Sree Binoy Krisna Ghosh	Ghoshpara	Private	519	10	-	1999	86	0.105	No water
287	Md. Sanarul Gazi	Gazipara	Private	881	40	-	1992	77	0.115	No water
288	Md. Manik Gazi	Gazipara	Govt.	832	60	-	1978	77	0.119	A little bit water
289	Sree Nirmol Ghosh	Ghoshpara	Private	533	40	-	1999	86	0.142	No water
290	Sree Gopal Ghosh	Ghoshpara	Private	517	25	-	1996	83	0.200	No water
291	Sree Lakkhi Kant Ghosh	Ghoshpara	Private	516	20	-	1992	68	0.178	No water
292	Sree Ziten Ghosh	Ghoshpara	Private	522	8	-	1996	80	0.246	No water
293	Md. Anwarul Islam	Ghoshpara	Private	524	30	-	2000	94	0.384	No water
294	Sree Bhaddrrassor Ghosh	Ghoshpara	Private	525	50	125	1982	92	0.203	Available water
295	Sree Gobinda Baddya	Baddyapara	Private	339	10	-	1997	68	0.350	No water
296	Sree Haridas Gain	Gainpara	Private	333	40	60	1995	68	0.281	Available water
297	Sree Baddya Ranjan Gain	Gainpara	Govt.	326	70	-	1985	68	0.258	No water
298	Sree Ashok Datta	Gainpara	Private	321	30	-	1986	86	0.266	A little bit water
299	Md. Monazat Sheikh	Sheikhpara	Govt.	301	60	-	1983	48	0.338	A little bit water
300	Md. Ziad Ali Gazi	Mathpara	Private	607	20	50	2000	52	0.383	Available water
301	Md. Sobhan Gazi	Mathpara	Private	546	5	15	1999	52	0.350	Available water
302	Md. Zainal Gazi	Mathpara	Private	489	20	35	1997	52	0.383	Available water
303	Sree Radha Pada Gain	Purbapara	Private	274	7	-	1992	71	0.281	No water
304	Md. Abdul Gani Gazi	Purbapara	Private	661	15	-	1997	71	0.350	No water
305	Sree Robin Mandol	Bakar Ghoz	Govt.	267	300	400	1998	180	0.020	Available water
306	Bakar Ghoz Primary School	Bakar Ghoz	Govt.	94	250	-	1993	68	0.276	No water
307	Sree Kali Pada Mandol	Uttarpara	Private	455	30	-	1987	83	0.103	No water
308	Sree Sachin Debnath	Uttarpara	Private	386	60	-	1995	77	0.339	No water
309	Sree Ratan Chandra Debnath	Uttarpara	Govt.	369	40	-	1983	42	0.261	No water
310	Md Auyub Hossain (Master)	Uttarpara	Private	368	20	-	1998	49	0.205	No water
311	Md. Shamsul Haque	Uttarpara	Private	356	30	-	1980	63	0.232	No water

APPENDIX – F (6)

ARSENIC DATA: WARD - 6, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Conditions
312	Chanka Zame Mosque	Uttarpara	Govt.	703	300	450	1997	180	0.093	Available water
313	Mohammad Ali	Uttarpara	Private	634	15	-	1986	74	0.107	No water
314	Md. Rajob Ali	Uttarpara	Private	972	10	25	1988	62	0.073	Available water
315	Md. Siddiqur Rahman	Uttarpara	Private	636	4	-	2000	77	0.310	No water
316	Md. Abdul Alim	Uttarpara	Govt.	613	20	30	1983	42	0.142	Available water
317	Md. Mizanur Rahman (Master)	Uttarpara	Private	613	20	-	1999	55	0.108	No water
318	Md. Ruhul Kuddus	Uttarpara	Private	686	5	-	1985	49	0.106	No water
319	Md. Mozam Sardar	Uttarpara	Private	691	25	-	1994	49	0.125	No water
320	Md. Zumman Molla	Uttarpara	Private	698	40	-	1995	92	0.011	No water
321	Md. Shahidul Islam	Uttarpara	Private	2108	45	-	1990	49	0.178	No water
322	Md. Rabiul Islam	Uttarpara	Private	2121	15	-	1994	75	0.303	No water
323	Md. Ziad Dhali	Choudalipara	Private	1855	50	-	1998	62	0.375	No water
324	Chanka Choudalipara Zame Mosque	Choudalipara	Govt.	1327	200	-	1997	55	0.428	No water
325	Md. Kashem Molla	Mollapara	Private	2327	70	-	1997	62	0.241	No water
326	Md. Hazrat Molla	Mollapara	Private	2333	35	-	1998	52	0.079	No water
327	Md. Atiuur Dhabok	Dhabokpara	Private	2148	30	-	1991	51	0.032	No water
328	Md. Shafiqul Dhabak	Dhabokpara	Govt.	2147	75	-	1983	42	0.110	No water
329	Md. Yaarul Islam	Dofadarpara	Govt.	2314	125	-	1983	42	0.104	A little bit water
330	Md. Deldar Rahman	Dakshinpara	Private	2306	75	125	1995	68	0.083	Available water
331	Chanka Dakkinpara Zame Mosque	Dakshinpara	Govt.	2281	70	-	1994	49	0.076	No water
332	Md. Gafur Sardar	Dakshinpara	Govt.	2281	50	-	1983	42	0.091	No water
333	Md. Amin Sardar	Dakshinpara	Private	2285	30	-	1990	49	0.036	No water
334	Md. Rezaul Islam	Dakshinpara	Private	2230	40	-	1998	86	0.251	No water
335	Md. Aminur Munshi	Dakshinpara	Private	2222	25	-	1995	68	0.288	No water
336	Md. Rostam Gazi	Dakshinpara	Private	2235	30	-	1992	62	0.142	No water
337	Md. Showkat Ali (UP Member)	Dakshinpara	Govt.	2260	300	500	1999	180	0.009	Available water

APPENDIX - F (7)

ARSENIC DATA: WARD - 7, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Conditions
338	Sree Bimol Krishna Ghosh	Ghoshpara	Govt.	905	50	-	1994	68	0.076	No water
339	Md Abdur Rauf (Master)	Kumarpara	Private	989	50	-	1993	49	0.266	No water
340	Md. Rajob Ali Molla	Kumarpara	Private	1003	15	-	1989	49	0.214	No water
341	Md. Abdar Rahman Molla	Palpara	Govt.	1017	20	-	1973	52	0.270	No water
342	Gazipur Primary School	Mollapara	Govt.	1051	300	-	1994	49	0.133	No water
343	Md. Atiuur Rahman	Mollapara	Private	1231	40	-	1994	28	0.142	No water
344	Md. Omar Ali	Mollapara	Private	1220	50	-	1990	60	0.480	No water
345	Sree Mangal Sarkar	Mollapara	Private	1213	50	-	1999	74	0.375	No water
346	Sree Tara Pada Sarkar	Daskhinpara	Private	1291	50	-	1985	43	0.067	No water
347	Sreemoti Renupada Sarkar	Maddyapara	Govt.	1284	15	-	1993	60	0.232	No water
348	Md. Tariqul Islam	Maddyapara	Private	1300	5	-	2000	62	0.241	No water
349	Sree Bijoy Krishna Mandol	Daskhinpara	Private	1319	10	-	1999	80	0.092	No water
350	Sree Haripada Master	Daskhinpara	Private	1312	45	-	1987	51	0.181	No water
351	Sree Hemanta Kumar Mandal	Mandolpara	Govt.	1364	60	-	1983	46	0.096	No water
352	Sree Kanai Mandal	Mandolpara	Private	1322	80	-	1997	52	0.096	No water
353	Sree Binoy Krishna Mandal	Mandolpara	Private	1326	50	-	1978	49	0.261	No water
354	Sree Shibnath Mandal	Mandolpara	Private	326	100	250	1975	49	0.073	Available water
355	Sree Rampada Mandal	Pashimpara	Private	629	20	-	1997	71	0.600	No water
356	Sree Nirapad Sarkar	Pashimpara	Govt.	393	125	-	1965	80	0.285	No water
357	Md. Akbar Ali	Mathpara	Govt.	1560	75	-	1995	80	0.232	A little bit water
358	Sree Ajit Kumar Pal	Palpara	Govt.	873	50	-	1983	42	0.065	No water
359	Md. Samadul Mandol	Palpara	Private	871	10	-	1996	49	0.232	No water
360	Md. Khorsed Alam (Khosh Lal)	Maddyapara	Private	868	75	-	1995	37	0.310	No water
361	Md. Rahim Gazi	Chowdalipara	Govt.	892	80	-	2000	42	0.428	No water
362	Sree Autul Sarkar	Maddyapara	Govt.	853	40	-	1994	62	0.285	No water
363	Md. Ashraf Ali Sardar	Sardarpara	Govt.	852	10	-	1995	55	0.181	No water
364	Md. Mantaz Muhuri	Sardarpara	Private	1031	20	-	1989	49	0.061	No water
365	Sree Bishwanath Sarkar	Chowdalipara	Community	843	200	-	1987	49	0.431	No water
366	Sree Kalipada	Sardarpara	Private	1250	25	-	2000	80	0.568	No water
367	Md. Ebadat Hossain	Sardarpara	Govt.	1262	100	150	1994	46	0.535	Available water
368	Sreekanth Sarkar	Sardarpara	Govt.	226	10	-	1996	55	0.314	No water
369	Md. Abdullah	Sardarpara	Private	240	50	125	1990	49	0.368	Available water
370	Sree Dron Sarkar	Maddyapara	Private	577	15	-	1992	43	0.466	No water
371	Sreemoti Taruni Sarkar	Maddyapara	Private	577	15	-	1997	77	0.470	No water
372	Sree Radhakant Sarkar	Maddyapara	Private	276	30	-	1997	55	0.515	No water
373	Sree Gopal Mukharjee	Maddyapara	Govt.	270	25	75	1995	68	0.464	Available water

APPENDIX – F (8)

ARSENIC DATA: WARD - 8, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Conditions
374	Md. Sekandar Ali	Pashimpara	Private	1786	10	-	1995	55	0.205	No water
375	Md. Harun-or-Rashid Sardar	Pashimpara	Private	4034	5	10	1992	80	0.285	Available water
376	Sree Surendranath Sarkar	Pashimpara	Govt.	4021	10	-	1983	43	0.275	No water
377	Sree Neetaipada Sarkar	Pashimpara	Private	4142	20	-	2000	69	0.339	A little bit water
378	Sree Horidas Sarkar	Pashimpara	Private	4152	40	-	1997	71	0.324	No water
379	Sree Binoy Sarkar	Pashimpara	Govt.	4164	25	40	1990	68	0.309	Available water
380	Sreemoti Kishori Mohon	Pashimpara	Private	4194	30	-	1985	66	0.285	No water
381	Md. Anisur Rahman	Purbapara	Private	4214	60	-	1996	49	0.375	No water
382	Md. Moslem Molla	Purbapara	Private	4213	50	-	1996	49	0.316	No water
383	Sree Gonesh Sarkar	Purbapara	Govt.	4229	60	80	1994	65	0.324	Available water
384	Md. Azizul Bari	Sardarpara	Private	4234	20	-	1993	55	0.339	No water
385	Mohadevnagar Zame Mosque	Sardarpara	Govt.	4244	100	150	1992	46	0.344	Available water
386	Md. Akbar Mandol	Majherpara	Govt.	4483	25	60	1995	57	0.362	Available water
387	Sree Dhirendranath Sarkar	Majherpara	Govt.	4473	50	-	1995	55	0.316	No water
388	Sree Robin Biswas	Biswaspara	Private	4494	70	100	1993	46	0.339	Available water
389	Md. Nurul Islam (Master)	Pasimpara	Private	4114	10	-	1992	68	0.300	A little bit water
390	Sree Anil Mandal	Majherpara	Private	4114	75	-	1983	48	0.327	A little bit water
391	Md. Nazrul Islam	Maddyapara	Private	4254	20	50	1999	74	0.300	Available water
392	Sree Binoy Krishna Mandol	Dakshinpara	Govt.	4408	50	-	1995	47	0.393	No water
393	Md. Harun-or-Rashid Gazi	East khalpar	Private	5610	25	-	1996	62	0.396	No water
394	Md. Mazed Master	Dakshinpara	Govt.	4400	20	-	1983	42	0.258	A little bit water
395	Md. Babul Gazi	Dakshinpara	Private	4412	25	-	1990	55	0.290	A little bit water
396	Md. Ibrahim Sardar	Dakshinpara	Govt.	4406	30	-	1997	49	0.329	A little bit water
397	Md. Shamsuddin Dhali	Uttarpara	Private	4624	60	-	1995	68	0.323	No water
398	Md. Lutfur Rahman	Uttarpara	Private	4623	10	-	1994	68	0.276	A little bit water
399	Md. Sahadat Hossain	Uttarpara	Private	4622	15	-	1998	46	0.285	A little bit water
400	Md. Hasanur Rahman Sardar	Nimtala	Private	4809	5	-	1996	55	0.420	A little bit water
401	Md. Royich Uddin	Nimtala	Govt.	4788	40	-	1997	40	0.357	No water
402	Md. Anwarul Islam	Nimtala	Govt.	4699	10	-	1997	51	0.382	No water
403	Md. Rabiul Islam	Nimtala	Private	4785	6	-	1999	74	0.321	No water
404	Md. Saheb Ali	Nimtala	Private	4764	4	15	1996	71	0.410	Available water
405	Md. Abdul Mazed Master	Nimtala	Private	4755	12	-	1990	46	0.178	A little bit water
406	Md. Abdur Rahim Morol	Nimtala	Govt.	4718	7	-	1995	58	0.442	No water
407	Md. Khadem Ali	Uttarpara	Govt.	4715	40	-	1995	55	0.250	No water
408	Md. Rowshon Ali	Uttarpara	Govt.	5049	30	50	1993	49	0.142	Available water
409	Md. Abdul Khaleque	Uttarpara	Govt.	5766	20	-	1986	73	0.140	A little bit water
410	Md. Monsoor Ali	Uttarpara	Private	5765	10	-	1993	54	0.123	No water
411	Md. Abdus Sabur	Uttarpara	Govt.	5745	50	-	1983	42	0.103	No water
412	Md. Abdul Malek	Uttarpara	Govt.	5760	40	75	1995	74	0.222	Available water
413	Md. Rajob Ali	Uttarpara	Govt.	5759	20	-	1996	52	0.178	A little bit water
414	Dr. Toufar Rahman	Uttarpara	Govt.	5747	300	450	1997	197	0.022	Available water
415	Md. Abul Kashem	Uttarpara	Private	5737	15	25	1997	62	0.178	Available water
416	Md. Rozo Ali Sardar	Uttarpara	Private	5736	5	-	1998	62	0.138	No water
417	Md. Zobed Ali Sardar	Uttarpara	Govt.	5750	10	-	1983	42	0.150	No water
418	Mrs. Rabeya Parveen (Member)	Sardarpara	Govt.	5649	30	45	1983	42	0.088	Available water
419	Md. Osman Goni	Sardarpara	Private	5636	10	-	1994	55	0.125	A little bit water
420	Md. Azizul Hoque	Sardarpara	Private	5631	10	-	1980	52	0.123	A little bit water
421	Md. Abdul Hamid	Sardarpara	Private	5635	20	-	1997	55	0.133	No water
422	Md. Sirazul Islam (UP Member)	Sardarpara	Private	5634	8	-	1992	52	0.136	No water
423	Md. Rowshon Gazi	Uttarpara	Govt.	5775	30	-	1980	49	0.080	A little bit water
424	Md. Abdul Gazi	Uttarpara	Private	5859	10	-	1995	62	0.106	A little bit water
425	Md. Akram Gazi	Gazipara	Private	5851	15	-	1996	49	0.126	No water
426	Md. Abdul Mannan	Uttarpara	Private	4730	12	-	1999	49	0.321	No water

APPENDIX - F (9)

ARSENIC DATA: WARD - 9, GHONA, SATKHIRA

TW_ID	TW holder	Para	Ownership	Plot	Users (Always)	Users (Seasonal)	Inst Year	Depth (metre)	Arsenic (mg/l)	Water Conditions
427	Ahsania Mission Zame Mosque	Bharukhali	NGO	5798	100	150	1990	46	0.251	Available water
428	Md. Abu Salek	Bharukhali	Govt.	5802	25	-	1983	42	0.198	No water
429	Md. Mobarok Morol	Bharukhali	Private	5803	7	-	1990	46	0.275	No water
430	Md. Nurul Islam	Bharukhali	Private	5804	5	-	1993	92	0.237	A little bit water
431	Bharukhali Zame Mosque	Morolpara	Govt.	5798	150	-	1950	48	0.178	No water
432	Md. Abdul Aziz Morol	Morolpara	Govt.	5789	350	450	1998	180	<0.003	Available water
433	Md. Mottalib Morol	Morolpara	Govt.	5787	25	-	1983	42	0.126	No water
434	Md. Noor Uddin Morol	Morolpara	Govt.	5784	20	-	1983	42	0.151	No water
435	Md. Afu Morol	Morolpara	Private	5624	10	15	1996	49	0.150	Available water
436	Md. Hakim Morol	Morolpara	Govt.	5624	40	-	1994	51	0.082	No water
437	Md. Arakan Morol	Morolpara	Govt.	5610	30	50	1950	48	0.151	Available water
438	Md. Rostom Morol	Morolpara	Private	5612	40	-	1990	49	0.076	A little bit water
439	Md. Ali Ahmed Gazi	Gazipara	Govt.	5587	20	-	1983	42	0.142	No water
440	Md. Assad Ullah Gazi	Gazipara	Govt.	5587	30	-	1983	42	0.214	No water
441	Md. Manik Gazi	Gazipara	Private	5585	20	-	1990	34	0.196	No water
442	Md. Golam Rahman	Gazipara	Govt.	5388	35	-	1983	42	0.155	A little bit water
443	Md. Shafiqul Dhali	Gazipara	Private	5583	40	-	1983	42	0.196	A little bit water
444	Md. Moyen Dhali	Gazipara	Govt.	5586	15	-	1983	42	0.227	No water
445	Md. Abdar Rahman	Gazipara	Govt.	5580	20	-	1983	42	0.196	No water
446	Md. Deldar Rahman	Gazipara	Private	5580	20	50	1996	43	0.160	Available water
447	Md. Anaruddin Gazi	Gazipara	Govt.	5579	60	-	1970	42	0.169	A little bit water
448	Md. Golam Bari	Gazipara	Govt.	5406	30	-	1995	42	0.241	A little bit water
449	Md. Moktar Rahman Gazi	Gazipara	Govt.	5572	20	-	1990	68	0.256	A little bit water
450	Md. Ansar Uddin Gazi	Gazipara	Private	5569	20	-	1995	42	0.205	A little bit water
451	Md. Nazrul Islam Gazi	Gazipara	Govt.	5575	300	450	1998	197	0.017	Available water
452	Md. Harun-or-Rashid (Haran)	Gazipara	Private	5523	30	-	1999	46	0.232	No water
453	Md. Shook Chand Gazi	Gazipara	Govt.	5502	20	-	1986	43	0.196	A little bit water
454	Md. Abul Gazi	Gazipara	Govt.	5473	50	-	1983	42	0.160	No water
455	Md. Mohsin Hafez	Biswaspara	Private	5815	20	50	1987	43	0.133	Available water
456	Md. Golam Rahman	Biswaspara	Govt.	5815	15	20	1990	45	0.169	Available water
457	Bharukhali Forkania Madrasa	Biswaspara	Govt.	5815	450	700	1997	200	0.023	Available water
458	Md. Minto Morol	Biswaspara	Private	5941	10	-	1990	48	0.232	A little bit water
459	Md. Rezaul Molla	Biswaspara	Private	5941	5	-	1990	55	0.214	A little bit water
460	Md. Sohel Uddin Biswas	Biswaspara	Private	5959	10	20	1995	46	0.080	Available water
461	Md. Humayon Kabir	Biswaspara	Private	5961	20	50	1995	35	0.196	Available water
462	Md. Fazlur Rahman Biswas	Biswaspara	Private	1963	15	-	1978	43	0.321	A little bit water
463	Md. Sahadat Biswas	Biswaspara	Private	5935	5	-	1985	49	0.079	A little bit water
464	Md. Samsur Rahman Biswas	Biswaspara	Private	5930	40	-	1999	52	0.178	A little bit water
465	Kalimondir (Temple)	Karmokarpara	Govt.	6387	50	-	1975	51	0.078	No water
466	Sree Baddyanath	Karikorpara	Private	6431	20	50	1997	46	0.160	Available water
467	Sree Tagor Chandra Paramanik	Paruipara	Private	6376	5	-	1993	43	0.085	No water
468	Sree Dhirendra Chandra Nath	Paruipara	Govt.	6291	20	-	1993	55	0.178	No water
469	Sree Ajit Sarkar	Purbapara	Govt.	6372	200	350	1997	191	0.007	Available water
470	Md. Shafiqul Islam (UP Member)	Purbapara	Private	5979	20	-	1990	45	0.151	A little bit water
471	Md. Abdul Karim Sardar	Purbapara	Private	5977	10	-	1992	49	0.133	A little bit water
472	Md. Abdur Rauf Sardar	Purbapara	Private	5984	10	-	1989	46	0.082	A little bit water
473	Md. Bazlur Rahman Biswas	Biswaspara	Private	5562	15	-	1988	45	0.032	A little bit water
474	Bharukhali High School	Biswaspara	Govt.	5026	350	-	1975	37	0.206	No water
475	Md. Shahidul Biswas	Mathpara	Private	4757	8	-	1995	71	0.392	No water

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